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ECONOMIC GEOLOGY OF THE BELGIAN CONGO, CENTRAL AFRICA.

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INTRODUCTION.

One who fifty years ago described the economic geology of the United States would have committed errors both of commission and omission, and the writers, in presenting this statement of knowledge of the economic geology of the Belgian Congo, are cognizant of the fact that the conclusions thereof will, in the future, be greatly modified.

Although for the past forty-five years mining men have shown an interest in South Africa, it is only during the last two decades that contributions of importance have been made to our knowledge of the economic geology of the Belgian Congo. The first important descriptions resulted from Professor Jules Cornet's visit to the Katanga copper and iron deposits in 1892. Since that time scientific and prospecting parties sent out by the colonial government and by private companies, have furthered the knowledge of the economic geology of the Belgian Congo. The difficulty, not only of satisfactory observation, but also of travel in tropical countries must explain, in part, the many shortcomings of this article.[2]

[1] Published by permission of the Société Internationale Forestière et Minière du Congo.

[2] For reviews of annual progress in mining see S. H. Ball, Mining and Scientific Press, Review for 1910, January 7, 1911; 1911, February 3, 1912,

LOCATION AND AREA.

The Belgian Congo lies in southwestern Central Africa to the west of the Great African Lakes. It has an Atlantic Coast line of but twenty miles, but widens rapidly eastward until it stretches to points five degrees north and fourteen degrees south of the equator. Its area is 908,000 square miles, or more than that of the United States east of the Mississippi River.

HISTORY AND PRODUCTION.

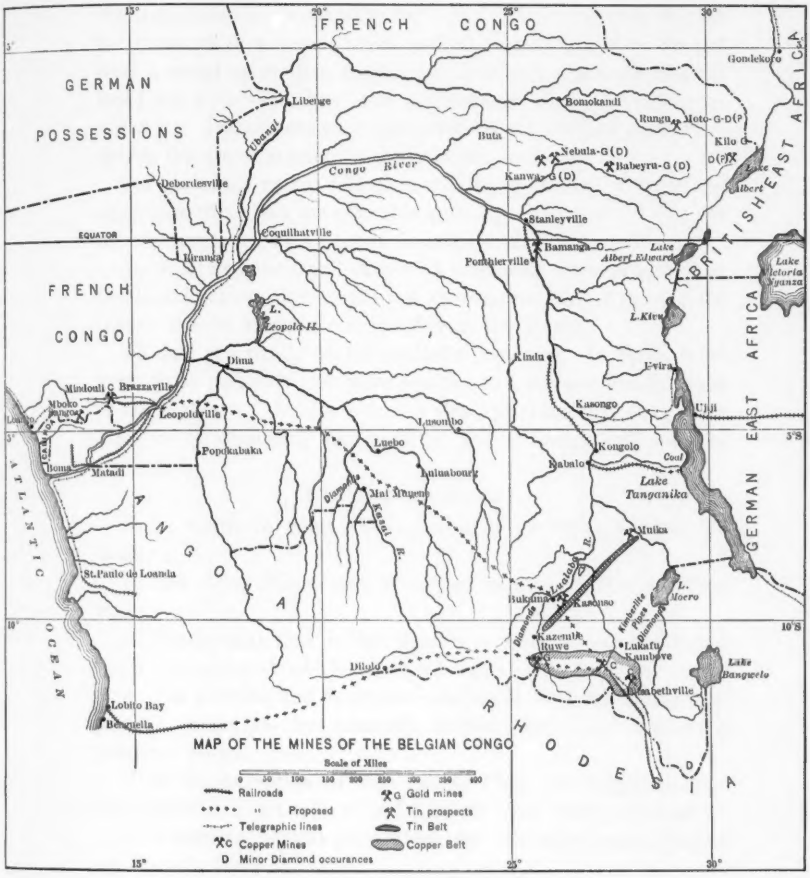
Iron and copper mines have been worked by the natives for centuries, and for at least 100 years some gold was won by the blacks for their Arab taskmasters from the Katanga streams (Plate XV.).

In the Katanga the white man began copper smelting about January 1, 1910, and between that date and the close of 1913, some 10,000 tons of copper have been produced. The present annual production is about equal to the above figure and further increases in the future seem assured. Prior to the white man's regime the blacks smelted many times this amount; Atherton[1] indeed believes that at least 100,000 tons of copper were produced, and that in the process the natives mined over 1,000,000 tons of ore and waste. One of the almost limitless number of ancient pits is 720 ft. long, 30 ft. deep, and 480 ft. wide at one end, tapering to a point at the other. At Bembe (Portuguese West Africa, or Angola), and M'Boko Songo and Mindouli (French Congo), the neighboring blacks also smelted considerable copper, and in the latter region a certain amount of lead.

Since 1904, when placer mining was begun on a small scale by white men, the colony has produced some $3,400,000 worth of placer gold. To this should be added an unknown, though probably small, amount of gold won in the early days, since Stanley reports that Zanzibarites, in his time, were washing some gold

pp. 132–36; 1912, April 19, 1913, pp. 576–82; 1913, February 21, 1914, pp. 320–25. S. H. Ball and M. K. Shaler, Transportation Facilities in Central Africa, Min. and Sci. Pr., April 12, 1913, pp. 538–42. General Mining Conditions, S. H. Ball and M. K. Shaler, *Trans. A. I. M. E.*, Vol. XLI., pp. 189–219, New York, 1910.

[1] T. W. T. Atherton, "The Copper Deposits of the Katanga," Leeds, 1907.



MAP OF THE MINES OF THE BELGIAN CONGO.

from the streams in the eastern portion of the Congo Basin, and Cameron states that the same traders got gold from some of the Katanga streams. Even when the Tanganyika prospectors entered the Katanga they were shown certain streams where in the old days a metal other than copper was won and when the Swahili word for gold "Zahabra" was pronounced one of the chiefs recalled it. The placers now operating should produce more than double the above amount in the next ten years.

For centuries native village smiths have smelted what in the aggregate must be a considerable quantity of iron ore. The ore usually employed as a porous limonite of recent formation.

Some fifteen thousand carats of diamonds were produced in the Kasai region, during the last two quarters of 1913, and the output should increase considerably in the future.

To date practically no tin has been produced. In 1906, however, some 10 tons of tin were smelted in a furnace locally made in the Katanga. Muika is now a small producer (in 1913 some 10 tons of cassiterite per month), and Busanga will soon be exploited.

PHYSICAL GEOGRAPHY.

From north to south Africa consists of three topographic units:

1. The Atlas Mountains, a rugged region of closely folded rocks.

2. The Soudan and Sahara deserts, a more or less accidented plain, the rocks of which are in the main horizontal and,

3. The Central and Southern tablelands, and the Abyssinian plateau, underlain by intensely folded older, and horizontal younger, rocks.

With the exception of the Coastal Plain the Belgian Congo lies within this last region, and consists from west to east of:

1. A narrow coastal plain along the Atlantic Ocean, flanked on the east by

2. An ancient mountain range, once peneplained, but now eroded to a highly accentuated plateau, and frequently referred to as the Crystal Mountains. The higher points reach an alti-

tude of 2,300 ft. The mighty Congo river, encountering the differently resistant rocks of this region, rushes through it in a series of rapids and low waterfalls, forming the non-navigable stretch between the lower and the upper Congo river.

3. The great interior region, a basin sloping gently to Lake Leopold II. (altitude 1,110 ft.). The limits of the basin to the north (altitudes from 2,500 to 4,200 ft.) and to the south (from 4,000 to 5,200 ft.) are not particularly mountainous, but to the east are

4. The Eastern Frontier mountains, in height averaging about one mile above sea-level, although Ruwenzori has an altitude of 16,800 ft. These mountains are in part due to folding, but largely to north and south faulting, and to some extent to genetically related volcanic phenomena.

Except for a small area in the extreme northeast watered by the Nile, the whole colony is drained by the Congo river and its tributaries. With the exception of Brazil, no tropical country is blessed with such a system of water-ways, as that offered by the Congo and its more important affluents, the Kasai, Sankuru, and Ubanghi. Bertrand[1] gives its length as 4,640 km. and states that the Congo is the sixth longest river in the world.

Contrary to general opinion, one half of the Belgian Congo is savanna, the other half forest. Practically all of the great equatorial forest lies between the fourth parallel south and the fourth parallel north, and most of it lies to the south of the great horseshoe bend of the Congo river. Elsewhere groves or even small forests are not unusual, yet the country is typically grass land with sparse and generally scrubby trees. A narrow fringe of dense forest usually, however, borders the streams.

The climate is tropical with heavy rainfall, high humidity, and relatively high, though diurnally variable, temperature. Abundant rainfall, or its absence, characterizes respectively a rainy and a dry season, except along the equator, where it rains more or less continuously throughout the year. A degree away from the equator, however, the seasons are well marked; the dry season

[1] "Le Congo Belge," 1909, p. 46.

which is considerably cooler, to the north of the equator, begins late in November and ends late in May, and is followed by the rainy season. February is very dry, and November the month of greatest precipitation. The seasons are naturally reversed south of the equator.

GEOLOGY.

The coastal plain is underlain by gently folded sandstones, limestones and shales of marine origin, which have a general inclination toward the ocean. These rocks, which are covered by recent alluvium at the Congo mouth, are, according to Zobinsky,[1] of Tertiary and Cretaceous age.

The so-called Crystal Mountains consist of rocks presumably of Paleozoic and pre-Cambrian age, which strike N.N.W.–S.S.E., with a predominant dip to the east. The older rocks of the series occupy the western portion of the belt, and the degree of metamorphism increases progressively from east to west. Apparently the oldest members are mica-schists and sericitic quartzites, interbedded with which are chlorite- and epidote-schists, representing either basic lavas, contemporaneous with the sedimentary rocks, or very ancient intrusive bodies of basic igneous rocks. Of later origin are intrusive granite and gabbro, now mashed and recrystallized into gneisses. Large bodies of massive granite and smaller ones of diabase intrude the foregoing. To the east of these rocks which, with the exception of the diabase, are considered presumably to be of pre-Cambrian age, are limestones and calcareous schists. These, near the ancient complex, are closely folded, but are flat-lying further east, half way between Matadi and Leopoldville. They are considered by E. Dupont[2] to be of Devonian age. To the east they are unconformably overlain by red sandstones, limestones, arkoses and shales, the Kundelungu (Permian) of Cornet.[3]

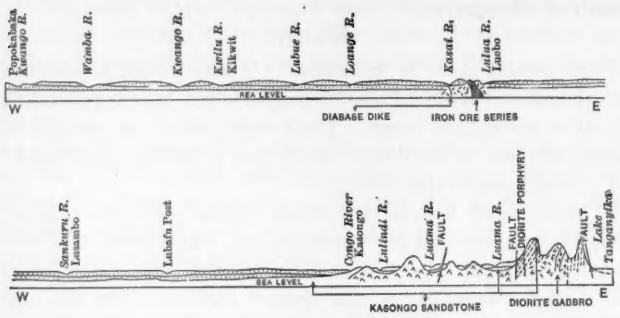
The interior basin is covered by interbedded sandstones and

[1] *Bulletin de la Soc. Belge de Geol.*, Vol. I, pp. 36–41, Mem. 1887.

[2] "Lettres sur le Congo," 1889, and *Bull. de la Soc. Belge de Geol.*, Vol. II., p. 47, 1888.

[3] *Bull. de la Soc. Belge de Geol.*, Vol. XXI., pp. 365–82, 1907.

shales of Jura-Triassic age,[1] which are either flat or dip gently towards its center. This Lubilache formation rests on the slightly undulating surface of the pre-Cambrian and Paleozoic rocks, and apparently in part feathers out on the upper slopes



GEOLOGIC SECTION ACROSS
BELGIAN CONGO FROM POPOKABAKA
EAST TO LAKE TANGANYIKA

SCALE
HORIZONTAL 1 INCH = 100 MILES
VERTICAL 1 INCH = 20,000 FEET

LEGEND

- Lubilache Sandstone
- Granite - Gneiss - Quartzite Complex
- Iron Ores
- Older Quartzite Schist
- Granite Gneiss
- Diorite Gabbros
- Granite
- Younger Quartzite Schist

PRE-CAMBRIAN

FIG. 133.

of the basin. As the border is approached isolated inliers of older folded and faulted rocks begin to appear in valleys which cut through the sandstone-shale blanket (Fig. 133).

These older rocks underlie the greater portion of the rim country, and are similar, in a general way, to those of the Crys-

[1] S. H. Ball and M. K. Shaler, *Jour. of Geol.*, Vol. XVIII., pp. 687–88, 1910.

tal Mountains. They consist of very ancient mica-schists and quartzites, and igneous schists and gneisses, which are intruded by gabbro and granites. Younger than many of the granites are folded sandstones, quartzites, slates, shales and limestones. Cornet, in referring these two series of rocks respectively to pre-Cambrian and Paleozoic time is, without much question, correct, although unfortunately, diagnostic fossils have never been found in the sedimentary rocks.

PRINCIPAL INTRUSIONS AND PERIODS OF DEFORMATION.

The supposed pre-Cambrian rocks of the Belgian Congo consist of a metamorphic sedimentary series with which are associated ancient igneous gneisses and schists, and granular igneous rocks. In at least the Tanganyika country there are two series of metamorphic sedimentary rocks of pre-Cambrian age, differing widely from one another in the amount of folding, faulting and intrusion, and consequent metamorphism suffered. The main structural features of the older rocks on the north and south rims of the Congo basin have an east and west trend, while the rocks of the eastern mountains strike north and south, and those of the Crystal Mountains, west of north to east of south. The older rocks thus trend as a rule parallel to the rim of the basin.

That the pre-Cambrian was a period of profound intrusion may be gathered from the fact that throughout the colony the following pre-Cambrian[1](?) rocks exist, beginning with the oldest:

1. Quartzites and schists of sedimentary origin,
2. Basic igneous schists probably partly lavas, contemporaneous with (1) and slightly younger intrusives,
3. Granite gneisses,
4. Diorite and gabbro, massive or slightly gneissic,
5. Granite.

The diabase, however, so frequently found cutting the above

[1] *Annales de Soc. Geol. Belgique*, 1913, "Mem. Pub. Rel. au Congo Belge," pp. 230–33, Liege, 1913.

rocks, is presumably in part, if not wholly, of post-Permian age. In the Crystal Mountains at least it is reported to cut the Kundelungu rocks.

During pre-Cambrian time there were several periods of folding, and at its end the land was raised above the sea, and appears in several regions to have been subjected to erosion until the Devonian. Elsewhere, however, as in the Katanga, where Cornet and Studt[1] have found sedimentary rocks, which they believe range in age from pre-Cambrian to Triassic, the colony appears to have been from the earliest periods to Lower Carboniferous time (according to Studt's latest work perhaps only to Devono-Silurian time), the site of a sea or succession of seas. In this region, in addition to pre-Cambrian granites which, if they are not certainly recognized in the Katanga by Studt, occur to the east of Lake Tanganyika on the Rhodesian-German East-Africa frontier, granitic intrusions mark the close of the Ordovician and mid-Devonian periods. The Ordovician granite was followed by magmatically related greenstone and in or prior to mid-Devonian times there was according to Studt a second period of greenstone (finely crystalline diorite) intrusion. Important folding occurred not only as elsewhere in the colony, according to Cornet, at the end of pre-Cambrian and in Middle (?) Carboniferous times, but also at the end of and in mid-Silurian time, or respectively according to the latest conclusions of Studt in pre-Silurian and mid-Devonian time. Prior to the deposition of the Kundelungu beds (Permian of most geologists) all important igneous activity, excepting unimportant diabase intrusions, appears to have ceased in most portions of the colony, although a few flows and pipes of basic lava, resembling Kimberlite and presumably of Cretaceous age, exist in Permian beds in the Katanga region, and dolerites[2] are interstratified with these

[1] Studt, F. E., *Trans. of Geol. Soc. of S. Africa*, Vol. XVI., pp. 44–106, Johannesburg, 1913; Cornet, Jules, *Ann. de la Soc. Geol. de Belgique*, Tome XXIV, 1897; Studt, F. E., *Annales du Musée du Congo*, Series II., Tome I., pp. 5–16, Bruxelles, 1908; H. Buttgenbach, *Ann. de la Soc. Geol. Belge*, Pub. Rel. au Congo Belge, Annex Tome XL., des Facs. II., p. 91, Liege, 1913.

[2] Studt, *Trans. Geol. Soc. of S. Africa*, Vol. XII., p. 165.

same beds in that region. According to Studt[3] some of these rocks intrude not only the Kundelungu beds, but also the Lualaba formation (Jura-Trias). He states "The rocks of the Kundelungu and Lualaba series are penetrated by a series of igneous rocks, forming sheets, sills and dikes, and belonging to the felsite, diorite, porphyrite, dacite, andesite, and basalt types. In the lower Lualaba valley large areas are covered by an amygdaloidal basalt flow which in places penetrates the beds of the coal formation (in part at least Lualaba in age. S. H. B. & M. K. S.) and probably corresponds in age with the Batoko Basalts of the Zambesia valley in the Victoria Falls district." Perhaps broadly related to these intrusions are some of the rather sparsely distributed diabase dikes of other portions of the colony already mentioned. In the northeastern part of the colony are Tertiary and recent volcanic rocks, some of the volcanoes of the Kivu region being now active. With the exception of the diamond-bearing pipes of the Katanga region, these post-Permian (if such be their age) igneous rocks are believed to be of no economic importance, and we are of the opinion that no metallic mineralization later than that of the Middle-Carboniferous was of importance in the Belgian Congo (or according to Studt's most recent work mid-Devonian).

With the beginning of Permian time, marine deposition ceased in the Belgian Congo, except on the coastal plain, and continental and fresh water deposits, derived from the eroded pre-Cambrian and Paleozoic rocks of the basin's borders, were laid down. The moderate relief of this old pre-Cambrian and Paleozoic plateau, except where affected by post-Mesozoic faulting, is a measure of the tremendous erosion suffered by this portion of Africa and the relative unimportance of post-Paleozoic movements. In the Kasai region at least prior to the deposition of the Jura-Triassic beds, the pre-Cambrian rocks were eroded to a peneplain from which but few monadnocks of resistant rocks arose. The Kundelungu (Permian) beds present in several portions of the colony were deposited after an important period of erosion, and are presumably continental deposits, while the Jura-

Triassic rocks were laid down partially on land (in part at least desert deposits), and perhaps partially as lacustrine and fluviatile deposits. In addition to a slight erosional unconformity between the Permian and Jura-Triassic beds, there is also between the two a slight discordance in dip, although important folding stopped prior to Permian time. Since the deposition of the Jura-Trassic beds it is probable that the central portion of the basin has sunk somewhat relatively to the rim region, although the quaquaversal dip is partially at least original. In the upper Congo river region from a point a short distance north of Kasongo, to its source, at several places morainal deposits[1] have been found, indicating that in late Permian or early Jura-Triassic time glaciers existed to the south.

In Mesozoic time the eastern portion of the colony was cut into several blocks by a more or less parallel system of north to south faults, by which the position of lakes Tanganyika, Kivu, Albert, Edward and Albert, and Upemba, and of the neighboring mountain ranges was largely determined. The earliest of these movements was according to Cornet post-Permian and pre-Triassic and according to Studt probably middle Devonian and certainly pre-Permo-Carboniferous.[2] Adjustment along these planes has continued to the present day, for this region is subject to rather frequent earthquakes and these faults are the sites of hot springs and volcanic phenomena.

The coastal plain in late Mesozoic and Tertiary time underwent several incursions by the sea, which were accompanied at one time or another by important faulting along the west front of the Crystal Mountains. These movements, however, within at least the Belgian Congo, were not accompanied by igneous activity, although Tertiary lavas are reported from farther south in Portuguese West Africa.

[1] Ball and Shaler, *Jour. Geol.*, Vol. XVIII., pp. 681–701, 1910.

[2] Studt, F. E., *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., pp. 44–106, Johannesburg, 1913. Cornet, J., *Annales du Musée du Congo*, Series II., Tome I., pp. 75–94.

GENERALIZATIONS CONCERNING ECONOMIC GEOLOGY.

The Belgian Congo, with the exception of the coastal plain, is an ancient plateau which has suffered successive erosional periods, not only in pre-Cambrian and Paleozoic times, but also a particularly important one continuing from Late Triassic to Recent time. The thickness of rocks removed must have been very great. Because of this and the fact that no intrusions of post-Middle-Carboniferous age (according to Studt's correlation mid-Devonian) are known to have been important metallic mineralizing agents, it is natural that those metals which, according to our present knowledge, are deposited near the surface (mercury for example), do not occur in important amounts. The ore deposits of the Katanga Paleozojc rocks, however, are not of deep-seated nature, as these rocks, though in places closely folded, have not been particularly deeply buried. In the pre-Cambrian rocks, however, which form large areas in the Katanga, and greatly predominate among the pre-Permian rocks in other portions of the rim regions, the majority of the ore deposits are of the types deposited at great depths, and those later to be found as mining progresses will probably be mineralized quartz lenses, magmatic segregations, sulphide and oxide segregations, and contact metamorphic deposits.

From the rather striking likeness of the pre-Cambrian rocks of the various portions of the colony, it is not surprising that their ore deposits throughout the colony have many points of similarity. The limited bulk of limestone in part accounts probably for the absence of important lead and zinc deposits, although the absence may be more apparent than real, as outcrops of lead and zinc ore are much more apt to be passed over in prospecting than the brilliantly hued surface showings of certain types of copper deposits. The almost complete absence of Tertiary intrusives and the depth of the erosion explains the non-presence of certain types of silver deposits, and if argentiferous ore bodies are later to be found, they will presumably be of intermediate or deep types.

In the northeastern part of the colony the gold mineralization

appears to be of pre-Cambrian age, and many of the lesser, commercially unimportant copper deposits, and most of the iron ore deposits throughout the colony are of similar age; indeed, metallic mineralization, with the exception of the Katanga Paleozoic tin and copper, the Ruwe gold deposits and the recent iron ores, is presumably largely pre-Cambrian. The diamond deposits at least those of the Katanga, are of post-Permian and perhaps of Cretaceous age.

The flat-lying sandstones and shales of the central basin are without important epigenetic deposits. They may possibly later be proved to contain locally lignite and petroleum. Stray colors of gold occur therein, and the placer diamonds of the Kasai region were probably weathered out of certain of their conglomerate beds. The original source of the precious stones, however, must be looked for elsewhere. The Tertiary and Mesozoic sedimentary rocks of the coast are known to contain sandstone with a high bitumen content, but otherwise appear to be barren. The recent gravels of the rim highlands contain in places concentration of the more resistant minerals, gold, diamonds, monazite, etc.

Although the greater portion of the central Congo basin is of little interest from a mining standpoint, the rest of the country may be considered rather well mineralized. Of particular interest to economic geologists are the Aruwimi-Uelle region in the northeast part of the colony; the Katanga in the southeastern corner adjoining Rhodesia, and the Kasai-Lovua region in the southwestern portion of the colony.

The analogy between the geology of the Central Africa plateau and of Brazil is close, as pointed out by Cornet, and to an equal extent the mineral resources of the two countries resemble one another. Not only are alluvial diamonds widely distributed over these two regions, but the mineral associations in instances resemble one another. In each country gold deposits are closely associated with hematitic quartzites. Further, there are similarities between iron ore deposits of the two countries and on the coasts of each occur bituminous sedimentary rocks of more or less importance.

COPPER.

Copper ores occur widely in the Paleozoic and pre-Cambrian rocks of the Belgian Congo. Of the deposits, by far the most important are those of the Katanga copper belt.

The Katanga Copper Deposits.[1]

The mining and smelting of copper ores has for centuries been an industry of the natives living in and near the Katanga copper field, and probably from the presence of stone implements of a still earlier race and the majority of the deposits of the Union Miniére du Haut Katanga (more familiarly known in England and America as the property of the Tanganyika Concessions Co., Ltd., which, however, has about a 42 per cent. interest in the

[1] Atherton, T. W. T., "Copper Deposits of the Katanga," July 31, 1907, Leeds. Ball, S. H., and Shaler, M. K., *Trans. A. I. M. E.*, 1910, pp. 260–64. Buttgenbach, *Mouvement Geographique*, No. 48, November 30, 1902, columns 577–85 (Kambove mine); *Ann. Soc. Geol. de Belgique*, Tome XXXI., 1903–1904, Mem., pp. 515–72; *Revue univ. des Mines*, etc., 4 Series, Tome XIV., 1906, pp. 114–147; *Bull. de la Soc. d'etudes coloniales*, 1906, Vol. XIII., June; 1908, Vol. XV., No. 2, February; *Annales du Musée du Congo*, Geologie, Series II., Tome I., 1908, pp. 17–51; "Conférence faite a la Soc. Belge des Ingénieurs et des Industriels le 18 Mars, 1908," Bruxelles. Cesaro, M., *Ann. de la Soc. Geol. de Belge*, Tome XXXIX., B, p. 241, Liege, 1912. Cornet, "Die Geologischen Ergebnisse der Katanga Expedition," *Peterman's Mitteilengen*, 1894; *Revue Universalle des Mines*, Series III., Tome XXVIII., 1894; Mem. de la Soc. des Sciences Lettres et Arts du Hainaut, Tome VIII., 1894; *Ann. Soc. Geol. de Belgique*, Tome XXIV., Mem., pp. 25–190, 1897, Liege; *Bul. de la Soc. Belge de Géologie*, etc. (Brux.), Tome XVI., 1902, pp. 651–56; Tome XVII., 1903, pp. 3–47; *Ann. du Musée du Congo*, 2d series, Vol. 1, pp. 75–94, Brux., 1908; "Katanga Province Belge," 1911, pp. 72–83; *Mouvement Geographique*, January 7, 1912, No. 1, 71. Farrel, J. R., Studt, F. E., Gray, Geo., Gibbs, A., etc., various reports, Tanganyika Concessions Co., 1906 to date. Farrel, J. R., *Eng. and Min. Jour.*, Vol. 85, No. 15, April 11, 1908, pp. 747–53. Geroke, A., "Die Berghauverhaltnisse im Kongo-Staate" *Berg- und Huttenmänn. Rundsch,*" Kattowitz, 1910. Guillemain, C., *Z. fur prak., Geol.*, 1913, pp. 320–37. Hennig, Dr. R., "Technik und Wirkschaft," Berlin, 1911, pp. 51–55. Lindgren, W., ECON. GEOL., Vol. VI., p. 575. Studt, F. E., *Ann. du Musée du Congo*, Geologie, etc., Series II., Tome I., 1908, pp. 5–16; *Trans. Geol. Soc. of South Africa*, Vol. XII., 1909, pp. 159–167; Vol. XVI., 1913, pp. 44–106. Stutzer, O., *Z. fur prak. Geol.*, 1911, p. 240, Addendum, p. 288 (L'Etoile du Congo Mine); *Metall. und Erz.*, Vol. X. (N. F. I.), heft 22, S. 679–86, August 30, 1913; *Z. fur prak. Geol.*, 1913, p. 478. Zimmerman, *Bull. Soc. Belge. Et. Col.*, 1910, pp. 595–600. Personal observations.

holdings of the above named company) are black men's mines which have been relocated by whites. At present three mines—the Star of the Congo, Kambove, and Luushia—are being exploited.

The Katanga copper deposits are situated in southeastern Belgian Congo, about 11° S. of the equator, and not far north of the Rhodesian frontier. Up to date about 160 deposits are known, within a belt extending 90 miles east from the Lufupa river, thence bending suddenly E.S.E. and reaching a point 110 miles distant. The cupriferous belt is from 30 to 60 miles wide. The Portuguese half-castes P. J. Baptista and Amaro José, who crossed Africa from Angola to Tete on the Zambesia in 1802, first mentioned this cupriferous region. Their description follows:[1]

"When we started from this farm of Chamuginga Mussenda (situated approximately 25° 10′ E. and 11° S. S. H. B.–M. K. S.), we travelled across others with valleys and hills, and saw, on the summit of the hills, stones which appear true (green?), and where they dig the copper; in the midst of this country is where they make the bars."

Livingston, Burton, Cameron, Joseph Thompson and Wissman, all heard from the natives that rich copper mines existed in the Katanga. Reichard[2] in 1884 was, however, the first white man to see them in the nineteenth century, and he was soon followed by Capello and Ivens, Portuguese travellers, and later by the Scotch missionary Arnot. It was, however, Professor Cornet who, in 1892, returned to Europe with the first satisfactory report upon these deposits.

The Katanga copper deposits are situated on a plateau whose surface has been cut by erosion into numberless rounded hills and rather steep-sided valleys. The geological structure indicates that the country in some time past was mountainous; was later,

[1] "The Land of Cazembe. Lacreda's journey to Cazembe in 1798. Also journey of the Pombeiros' P. J. Baptista and Amaro José across Africa from Angola to Tette, on the Zambeze," Royal Geog. Soc. London, John Murray, 1873, pp. 221–22.

[2] "Reise noch Urua und Katanga," *Mittheil du Afrikan Gesell. in Deutschland*, Vol. IV., No. 5, pp. 303–307, 1885.

as Cornet[1] holds, peneplained and still later eroded into its present rugged form: erosion has hence been rather deep. Elevations of the higher hills and the lower valleys are respectively 5,200 and 3,900 ft. above sea-level.

The copper bearing strata are harder as a rule than the asso-

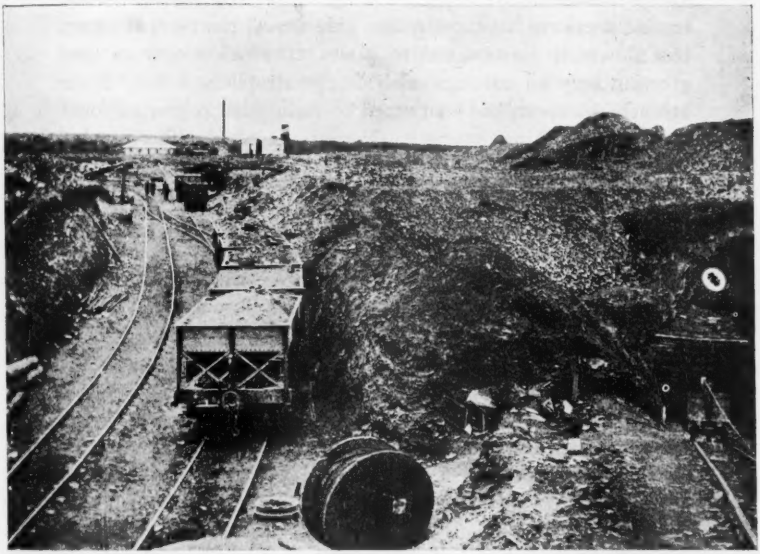


FIG. 134. Deforested condition near Star of Congo Mine. (Photo by E. Sengier.)

ciated rocks and, in consequence, the ore deposits usually form cones or ridges. One or two of the deposits, notably Luushia, however, occur below low-lying land.. The mineralized hills, in contradistinction to the surrounding timbered country, are bare, and between them and the forest grows the misuku or mahobo-hobo bush (a wild species of loquat), which is here a most ex-

[1] Cornet, *Annales du Musée du Congo*, Series II., Tome I, Bruxelles, 1908, pp. 92–93.

cellent indicator of copper. (Fig. 134.) This deforestation, due possibly to the presence of soluble copper salts in the soil and subsoil, has been a valuable aid in prospecting, as has the topographic relief of the deposits. C. Guillemain,[1] however, believes that the lack of trees is due rather to the soilless rocky outcrop of the hard beds of copper bearing rocks, and states that all treeless areas are not cupriferous. He found, however, an azure blue flower to be confined to places at which copper occurs, growing only on outcrops, slag dumps, or piles of ore. Such bareness, however, has been noted by us in other copper regions, and probably is in part due to the presence of cupriferous solutions in the soil.

Studt[2] finds the rocks of this portion of the Katanga to consist, in addition to various igneous rocks, of a series of sedimentary rocks, largely quartzose. From lithologic resemblance to those of Rhodesia and South Africa, he believes them to range in age from pre-Cambrian to Permo-Carboniferous. The oldest rocks, the Kafubu beds (supposed to be the equivalent of Rhodesian Swazi schists and probably at least of Cambrian age), consist of compact granular quartzites, usually white or pale red in color. Near granite intrusions, they pass to quartz and mica schists. Upon this lies unconformably the Wemashi beds consisting of dark colored conglomerates, greywackes and shales. These rocks are taken to be the equivalent of the Black Reef series of the Transvaal system and are hence of middle Silurian age. Passing gradationally upward from the last are the Kambove beds, consisting of grey dolomites, sandstones and shales more or less pyritic. The bedding planes of these rocks have been obliterated at most places by the development of cleavage. The dolomites, which owe their color to carbonaceous matter, contain much chert. These beds also are supposed to be equivalent to the Black Reef series. On these conformably lie the Lufira beds, consisting of fine-grained brick-red sandstone and shale with interlaminated brownish sandstone and red and white

[1] C. Guillemain (*op. cit.*), p. 324.

[2] Studt, F. E., *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., 1913, pp. 44–106.

banded shales and a few thin beds of red dolomite. This series is supposed to be equivalent to the Pretoria series of Transvaal and is hence of Devono-Silurian age. Studt states that the Kundelungu sandstones lie on these rocks without stratigraphic break and are equivalent to the upper part of the Pretoria series or are of Devono-Silurian age. This, however, is directly contrary to his former conclusions and to those of Cornet, that these beds are the equivalent of the Karroo sandstone and hence are of Permian age. He further believes that the Lubilasche sandstone beds of Katanga, which lie unconformably on the Kundelungu, are the equivalent of the Waterberg system (hence Devono-Carboniferous), and that these are overlaid unconformably by the Lualaba coal-bearing shales, which later he correlates with the Ecca beds of the Karroo. Other students of Katanga geology however regard the Lualaba as older than the Lubilasche and of Jura-Triassic age. Certainly, this is the relation of lithologically similar rocks in other portions of the Colony, with the geology of which the authors are more familiar. In an earlier work in which the correlations were respectively Wemashi, Upper Silurian; Kambove, Upper Devonian; Lufira, Lower Carboniferous; and Kundelungu, Permian, Studt is in accord with other students of the region,[1] but due to his many years of field work as geologist for the Tanganyika concessions company, his more recent conclusions should be accepted, particularly in regard to his correlation of the older rocks. Xhignesse and Mercenier[2] have recently done careful work in the Lukuga coal basin and find the Kundelungu beds to lie conformably upon the coal bearing measures which enclose Permo-Carboniferous plant remains. In consequence, for the present at least, we must consider the Kundelungu as of Permian and the Lubilasche as of Jura-Triassic age.

Most of the copper deposits occur in the Kambove and Lufira rocks, some, however, in the Wemashi beds. The copper bearing strata consist of sericite schists and quartzose rocks, varying

[1] *Annales du Musée du Congo,* Series II., Tome I., Brux., 1908, pp. 5–16.

[2] *Revue Universelle des Mines,* etc., 5me Série, Tome I., 1913, Liege, pp. 142–48.

from soft shaly sandstone to pure quartzite, and in instances include also slate, dolomite, and a cellular quartzose rock. These rocks are usually of light color near the ore deposits, because of bleaching. The interbedded reddish sedimentary rocks are barren.

Cornet[1] states that these rocks in Middle Caboniferous time,

FIG. 135. Star of Congo Mine, showing steep dip of bedded deposits. (Photo. by E. Sengier.)

were compressed into two systems of contemporaneous folds, junctioning near the Ruwe gold mine. The axes of one set in the Lualaba region extend from N.E. to S.W. and those of the second in the central and southern portions of the Katanga, course from W.N.W. to E.S.E. Studt, on the other hand, believes that the former were developed in pre-Silurian time and

[1] Cornet, *op. cit.*, pp. 75–94.

the latter in mid-Devonian time. The predominant dip of the W.N.W.–E.S.E. folds is to the north. The majority of the copper mines are strung along like beads on chains in lines parallel to the latter folds.

The ore deposits are characteristically associated with sharp

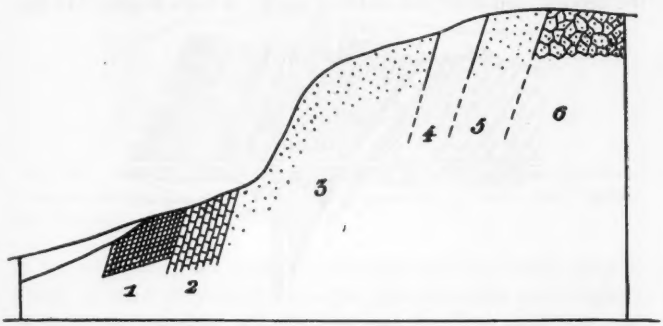


FIG. 136. Section of Lukasi copper deposit, Katanga. 1, hematite; 2, barren gray limestone; 3, 5, malachite-bearing sandstone; 4, pulverent oxides of iron, manganese and copper with malachite and chrysocolla; 6, quartzite with malachite in fractures and vugs. After Buttgenbach, *Annales du Musée du Congo,* Series II., Tome I., p. 30.

folding, faulting, brecciation, and an unusual degree of metamorphism (Figs. 136 and 137, 135). The ore bodies vary in size from comparatively small to large ones, the largest of which Kambove No. 2 is reported to be 3,000 ft. long and so far as tested, from 240 to 400 ft. wide. The ore as a rule impregnates a sedimentary bed or several beds rather sharply defined from the barren country rock. In several cases ore bodies occur in well defined anticlines, and in one case presumably in a syncline (Figs. 138 and 139). The deposits are tabular lenses, and in the greater number of cases, the ore body follows the dip of the country rock. The ore within each sandstone bed is discontinuous, but in the same bed several lenses may replace each other along the strike. Studt notes the fact that ore in instances may occur on but one side of an anticline or syncline. In instances,

according to Stutzer,[1] the ore cuts across bedding planes and follows secondary structures such as schistosity. Studt[2] regards the quartzose cellular rock as a silicified dolomite altered by the mineralizing solutions which deposited the copper ores. The ore beds parallel this breccia, which is frequently in the center of the deposit, and cross the bedding planes at high angles. In the

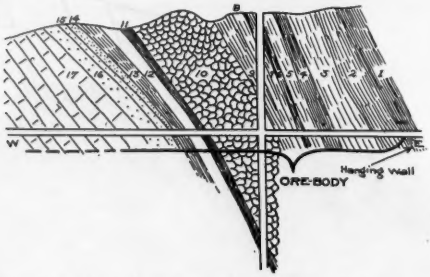


FIG. 137. Cross section of main ore body, Star of Congo mine; scale 1 inch = 50 ft. 17, dolomite ore—used for fluxing; 16, 15, flaggy sandstone; 14, hard flagstone practically barren; 13, ferruginous schist; 12, black ore carrying considerable cobalt and good copper content; 11, hard schist; 10, cellular quartzose rock; 9, siliceous schist; 8, schist; 7, laminated schist; 6, nodular schist; 5, laminated schist; 4, siliceous schist; 3, fissile schist; 2, green schist, "green ore"; 1, soft talcose-shaly schist, "Talcose ore."

Kansanshi mine, a presumably similar deposit, across the Rhodesian frontier, the copper ore occurs in vertical fissures at right angles to the stratification. The ore usually preserves its width in the upper silicious beds, but splits into stringers in the underlying dolomite, which contains disseminated chalcopyrite grains. At the Star of the Congo mine, Studt states that the ore in depth is parallel to the cleavage rather than the bedding planes and that the superficial oxidized ore is replaced in depth by pyritiferous dolomite.

The quartzose cellular rock which is much fissured, contains large masses of copper carbonates and oxides. Away from this

[1] *Metall. und Erz., loc. cit.*

[2] *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., 1913, Johannesburg, p. 52, also p. 68.

quartzose band the country rock is impregnated more or less completely with malachite, chrysocolla and azurite. In schists, thin sheets of these minerals occupy the closely spaced schistosity-planes in such a way as to remind one, looking across the schistosity, of a book whose leaves are alternately green and white.

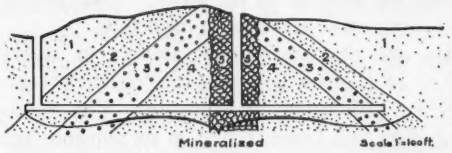


FIG. 138. Musonoi copper deposit, Katanga, showing anticlinal structure. 1, barren sandstone; 2 and 4, sandstone; 3, quartzite; 5, "crush rock" (silicified dolomite). Adapted from Atherton.

In the sandstones, the plates of malachite are less closely spaced. Finely divided chrysocolla, azurite and malachite also impregnate the various mineralized rocks, and the three minerals, frequently closely interbanded, occur in botryoidal and mammillary masses filling joint and breccia fractures. Atherton states that the amount of copper ore present varies directly with the porosity of the containing rock. Sandstones, once porous, are com-

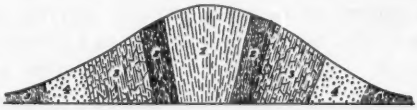


FIG. 139. Cross section of Kimbui copper deposit, Katanga, showing probable synclinal structure. 1, Silicious schist with many quartz veins; 2, filmy schist; 3, iron stained, brecciated schist; 4, cavernous quartzite; 5, soft fissile white schist. From Cornet, *Bull. Geol. Soc. de Belgique* (T. & R.), Tome XVII., 1903, p. 28.

pletely filled by copper ores, but massive flagstones are barren except for ore in fractures.

The most abundant copper minerals are malachite and chrysocolla; azurite, copper pitch ore, and melaconite are less abundant. Cuprite, dioptase, native copper, lunnite, libethenite, olivenite,

and cyanotrichite are rare, as is also a blue crystallized phosphate of copper and cobalt,[1] presumably a new mineral found at the Star of the Congo mines. Buttgenbach[2] reports the presence of two generations of malachite; an older, contemporaneous with the original gangues of the ore, and a younger, deposited in cavities from the solution of the other. Studt states that cuprite alters to melaconite and then to malachite.

Sulphides are characteristically absent; in native pits at Luushia 6 to 12 ft. deep, however, chalcopyrite[1] occurs in shale with malachite, psilomelane and limonite. The chalcopyrite alters to malachite and limonite, and in consequence some of the malachite at least was derived from the alteration of sulphides. Chalcopyrite has also been found in veinlets at Kambove and, at the Musonia mine, impregnates sandstone. Both chalcopyrite and pyrite in small quantities were encountered in drill holes at the Star of the Congo mine at a depth of 60 meters. Atherton reports pyrite at Kabolola, and believes copper glance to be present at Kambove. Studt mentions likewise the presence of chalcocite and also of bornite and covellite. The unimportance of sulphides is rather remarkable, in view of the fact that water level at the Star of the Congo mine is at a depth of about 50 ft., and at Kambove presumably at about the same depth.

Cobalt is present as an oxide, probably carrying manganese, according to Guillemain, also presumably as a phosphate of copper and cobalt. Calcite, quartz (both crystalline and chalcedonic), dolomite, limonite, hematite, and manganese oxides (both psilomelane and braunite) are commom gangues. Barite occurs also at Kambove mine No. 1 and Buttgenbach reports that there a bituminous substance is associated with copper oxide and pulverulent manganese oxide. Hematite is not only intergrown with malachite but also forms bed-like bodies in the vicinity of the copper deposits. Magnetite crystals and graphite (Atherton and Buttgenbach) are presumably to be considered as original constituents of the country rock.

[1] M. Cesaro, *Ann. de la Soc. Geol. de Belg.*, Tome XXXIX., B, p. 241, Liege, 1912.

[2] Buttgenbach, *Ann. du Musée du Congo*, Series II., Tome I., Bruxelles, 1908, p. 40.

The ore is of good grade and Atherton estimates that in twelve of the larger deposits there is ore carrying from 6.3 to 14.4 per cent. copper, equivalent to 1,177,960 long tons of copper. The ore is either silicious, aluminous, talcose, ferruginous or dolomitic. Of these the silicious ores are most abundant, Atherton[1] stating "the general average being from 51 to 63 per cent. of silica; extreme cases go to 83 per cent."

Typical analyses are given in the accompanying table:
Although the Star of the Congo ore carries no appreciable quantity of precious metal, in the other mines traces at least of gold and silver are usually present. The gold varies from 0 to 3 grams per ton, and silver reaches a maximum of 72 grams. Although small placers are derived from the copper deposits (see page 22), Buttgenbach in panning the copper ore of the Kambove mine itself, failed to get a color. The amount of cobalt is notable. In 1911, the crude copper from the Star of the Congo mine contained about: copper 89–90 per cent., cobalt 5.5 per cent., iron .3 per cent., and sulphur 1.1 per cent., and shipments the past summer (1913) analyzed as follows: copper 89.85, cobalt 3.25, iron 1.8, and sulphur 0.8 per cent.

The Katanga copper deposits are quite similar in mineral paragenesis and in form, and probably all have a common origin. Cornet believes these deposits to be the "iron hats" of copper sulphide bodies, as does Buttgenbach, who expects further that the sulphide body will consist of chalcopyrite, bornite, hematite and magnetite, in a vein or veins parallel to the bedding of the sedimentary rocks. He states that the rocks containing the copper ores were folded in Middle Carboniferous time, and that the ore deposition was of similar age. Studt believes them to be deposited by magmatic waters connected with a granitic intrusion of Mid-Devonian age. Stutzer is also strongly inclined to believe that the Star of the Congo mine is situated on the oxidized portion of a sulphide vein. Stutzer[1] states that the Katanga ore bodies are similar to that of Bwana M'Kubwa, situated in Rhodesia, on the Belgian Congo frontier, at no very

[1] Atherton, *loc. cit.*, p. 10.

TABLE OF ANALYSES, KATANGA COPPER ORES.

	No 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	55.62	58.40	67.19	74.21	34.9	33.80	46.60	8.00	28.95	57.40	43.70	47.00	55.40	74.40	61.65	66.40
Al_2O_3	2.65	5.90	5.67	3.85	16.6	10.50	12.70	——	8.60	12.28	11.69	11.43	4.40	2.46	4.04	4.32
FeO	6.75	6.60	5.81	3.79	6.50	6.50	3.70	——	25.10	4.88	2.40	3.50	2.50	2.25	2.73	4.27
MgO	3.05	6.50	2.31	2.35	13.70	14.00	14.40	20.00	2.37							
CaO	Traces	0.40	——	0.05	——	0.20	0.20	27.00	2.26							
CaO and MgO										1.95	8.95	10.82	6.06	3.18	5.90	5.74
Copper	8.	8.60	7.10	6.63	11.30	13.50	8.10	1.20	15.20	12.45	15.20	14.13	16.26	8.79	13.53	13.03
Cobalt	0.24				——	2.00										
Phosphoric acid	0.13							(CC$_2$) 43.40								
Loss					12.2	19.50	10.80	0.40								

Nos. 1, 2, 3, 4. Siliceous ores, Star of Congo mine.
Nos. 5, 6. Aluminous or "green" ore: green schists in hanging wall, Star of Congo mine.
No. 7. Talcose ore in hanging wall, Star of Congo mine.
No. 8. Dolomitic ore in foot wall, Star of Congo mine. (Another analysis shows 1 per cent. of Al_2O_3.)
No. 9. Black ore, no. 12 of section, Star of Congo mine. (Fig. 137.)
Nos. 10 to 16. Analyses from north and south levels, Kambove mine.

great distance from and on the strike of the Katanga belt. Certainly, from Speak's recent report[1] the country rock is similar even

[1] S. J. Speak, *Mining Magazine*, p. 299, 1913, London.

to the silicified dolomite, although the amount of chalcocite present with depth is considerably greater. Speak apparently considers the Bwana M'Kubwa ore bodies to have been deposited by ascending water. Until the cellular quartzose rock, frequently associated with the deposits, was proved to be silicified dolomite, the inference that the original deposits were veins, with the country rock nearby more or less impregnated with chalcopyrite or some other sulphide, was not untenable. The small quantity of sulphides found to date, notwithstanding the fact that exploration has extended to depths at which under similar climatic conditions, the zone of secondary enrichment at least should have been encountered, is rather against the idea that these are veinlike bodies. The data now at hand appears sufficient to prove that these deposits are not veins.

Atherton believes that the ore bodies were deposited by descending waters which derived their copper content from the decomposition of an overlying bed containing either cupriferous pyrite or chalcopyrite, he having identified remnants of this overlying formation to his own satisfaction. He states that the ore bodies decrease in copper content with depth, and believes that the richness of the various deposits is determined by the depth to which erosion has cut. In the more deeply eroded deposits the amount of copper, iron, manganese and cobalt decreases, and the relative proportion of copper silicate increases over that of malachite.

Lindgren[1] suggests that the ore bodies belong to the class of bedded copper deposits lying in sandstone and not dependent in origin upon igneous rocks. The copper deposits in the Red Beds of New Mexico are typical examples. We understand this, namely a sedimentary origin, is also espoused by one of the more capable mining engineers who has examined the field. C. Guillemain, in a recent rather complete paper argues along similar lines, namely that beds of copper ore of sedimentary origin were changed by dynamic metamorphism. He, however, admits that

[1] Lindgren, ECON. GEOL., Vol. VI., p. 575.

mining has not proceeded to sufficient depths to definitely settle the question of origin. From Cornet's[1] description, the ore, as is characteristic of many copper deposits of this general class, occurs in gray or white beds, and the intercalated reddish beds are usually barren. The presence of deposits in several rock series widely separated stratigraphically requires a re-occurrence of similar and unusual conditions of sedimentation which is, however, to our minds, not in favor of this hypothesis and the reported dependence in certain instances of the ore bodies upon secondary rather than original structures is of similar import.

Our personal observations are too limited to speak authoritatively upon the origin of these deposits. They were perhaps, however, formed by ascending waters, as were the rather similar copper deposits of Atbasar, in the Kirghese Steppes, Siberia; deposition having taken place partially through cavity filling in highly fractured areas, and partially by the replacement of peculiarly favorable rocks. Whether or not these waters were meteoric and under artesian pressure, or were remotely connected with some magma, is, of course, most speculative. Igneous rocks are not absent, as in addition to the granite of Mid-Devonian age, which occurs near some of the ore bodies in the southeastern end of the belt, there are in the Star of the Congo mine, according to Studt,[2] several dikes of minette or mica-syenite. To the north of this belt the apparently similar copper deposit at Kapula, of which the ores and the mineralized rocks are like those of the copper ore bodies in the main belt, according to Gwyn-Williams,[3] occurs along a granite contact.

THE BAMANGA COPPER DEPOSIT.

This deposit, which was casually examined by one of us some time ago, lies on a small island in the Congo river about seven miles below Ponthierville. It was for a time actively developed

[1] Cornet *Bull. Geol. Soc. de Belge,* Tome XVII., 1903, pp. 24–35.
[2] *Trans. of the Geol. Soc. of S. Africa,* Vol. XVI., 1913, Johannesburg, p. 69.
[3] Gwyn-Williams, R. H., *Mining Journal,* August 30, 1913, p. 839.

by a subcompany of the Grand Lakes Railroad, but is now moribund.

The country rocks noted are a red arkostic sandstone or quartzite (Permian?), which is undoubtedly younger than a coarsely porphyritic biotite-granite gneiss (pre-Cambrian?), with which it contacts. With the granite gneiss is a little hornblende-biotite gneiss, evidently representing a mashed basic igneous rock. These rocks dip steeply, the strike being roughly E.W. The ore occurs in parallel fissure veins, cutting all the country rocks, or what is equally probable, in short lenticular bodies, deposited in discontinuous fractures, some of which at least are faults. These ore-bodies, as exposed in open cuts, vary in widths from 0.5 to 2 ft., and strike a little east of north. Quartz, chalcocite chalcopyrite and fragments of country rock, are the vein filling. The first two are frequently well crystallized in vugs, and the chalcocite has been crystallographically studied by Buttgenbach.[1] Chalcopyrite alters to azurite and malachite, with some native copper, cuprite, and bornite. Picked ore runs from 31 to 55 per cent. of copper, and appreciable quantities of gold and silver are reported to be associated with it. Along the Congo river copper placers (thin beds of pebbles of rich copper ore interstratified with recent river sands) are reported to exist. Small gold placers are associated with the latter, and near the copper deposit native gold and silver occur in iron stained fractures.

OTHER COPPER DEPOSITS IN THE BELGIAN CONGO.

Copper occurrences, none of them of proved importance, are reported in the Paleozoic and pre-Cambrian rocks from many localities, particularly in the eastern and southern portions of the colony. They include the following types:

1. Cupriferous quartz veins. Near Siku M'Bidi, about 70 miles south of east of Kasongo, is a quartz vein 8 ft. wide, and traceable about 100 ft. The quartz contains a fair proportion of chalcocite, chalcopyrite, and bornite partially altered to malachite,

[1] Buttgenbach, "Extrait des Annales du Musée du Congo Belge," Bruxelles, 1910, pp. 13–18.

and a little azurite. Cupriferous quartz-calcite veins occur in the same region. The country rock is pre-Cambrian schist. F. F. Mathieu[1] describes a small copper deposit in the Lubudi limestone (presumably lower Carboniferous) at Kitalla, in Lower Katanga. The vein is from 0.6 to 1 meter wide, and consists of quartz, containing slightly argentiferous galena, chalcocite, malachite, azurite, limonite and chalcopyrite.

2. Lenses of chalcopyrite in schists and their presumably secondary form, heavily malachite impregnated schist.

3. Magmatic segregations described by Guillemain[2] from the pre-Cambrian of the Katanga region. In the Lower Congo chalcopyrite or cupriferous pyrite is an abundant accessory of diabasic rocks.

4. Bedded deposits of copper in red sandstone beds: It is stated[3] that at many places in the Katanga bedded deposits of copper sulphides occur in the practically flat Kundelungu beds. The deposits, which are small and pockety, have no known relation to igneous rocks. Cornet reports veins of copper also in these rocks. Guillemain believes the former to be bedded deposits of sedimentary origin. The presence of such deposits was to have been expected, for these Kundelungu beds according to most Congo geologists belong to the great class of "Red Beds," of Permo-Carboniferous age, which throughout the world have parallel to their bedding planes oxidized or sulphide copper ores, which ores, in part at least, are of sedimentary origin.

GOLD.

Lodes.—Lode prospecting to date has consisted largely in tracing placer gold to its source, and has as yet located no veins of importance. At some future date, however, important gold de-

[1] F. F. Mathieu, *Ann de la Soc. Géol. de Belge*, Pub. Rel. au Congo Belge, 1911–1912. Annex au Tome XXIX., des Annales Fas. III., Liege, 1913, p. 189.

[2] Guillemain, *loc. cit.*, p. 322.

[3] Studt, F. E., *Trans. Geol. Soc. of S. Africa*, Vol. XII., pp. 164, 166–67; Cornet, "Le Katanga Province Belge," p. 82. Gwyn-Williams, *G. R. H. Mining Journal*, London, August 30, 1913, p. 839. Guillemain, *loc. cit.*, p. 322.

posits may be found not marked by important placers, like the Tertiary gold ores of the west of the United States. Quartz is common in all Paleozoic and pre-Cambrian rocks, particularly in the schists. Some occurs undoubtedly in fissure veins, while other quartz forms lenses or series of lenticular bodies. Some of this quartz is barren. Some however contains pyrite, chalcopyrite, arsenopyrite, and other sulphides, and is more or less auriferous. Pyritiferous schist belts are also at several places known to be gold-bearing. To date the one gold lode which has been carefully examined, Ruwe in the Katanga, is strikingly similar to the copper deposits of that region.

Ruwe Gold Deposits.—At Ruwe,[1] which is situated near the source of the Lualaba river, about eight years ago the detrital deposit below the lode was sluiced and some 10,900 ounces of gold won. Operations have since ceased.

The country rocks are sandstones and quartzites of the Kam-

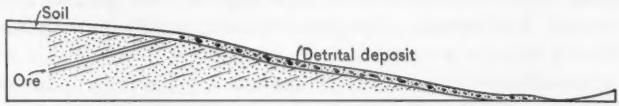


FIG. 140. Cross section of Ruwe gold deposit. Approximate scale 1 inch = 400 ft. Buttgenbach, *Annales du Musée du Congo,* Series II., Tome I., p. 59.

bove system (Middle Silurian according to Studt), which dip from 12° to 35° N.N.W. and are cut, as is the ore body, by faults trending N.W.–S.E. (Fig. 140). At the surface the rocks on either side of the lode carry values, but at a few meters depth the ore body consists of a single indurated banded sand-

[1] Ball, S. H., and Shaler, M. K., *T. A. I. M. E.,* Vol. XLI., pp. 259–60, 1910. Buttgenbach, H., *Bull. de la Soc. Belge de Geol.,* Tome XVIII., Bruxelles, 1904, Mem., pp. 173–86; *Ann. de la Soc. Geol. de Belge,* Tome XXXIII., Mem., pp. 51–70, Liege, 1905–1906; *C. R. du Congrès Internationale des Mines,* etc., Sect. de Geol. appliquee, Liege, 1905; *Ann. du Musée du Congo,* 2d Serie, Vol. I., pp. 57–69, 1908, Bruxelles; *Revue Universelle des Mines de la Métallurgie des Travaux Publies,* etc., 4th Serie, Vol. XIV., pp. 114–47, 1906. Farrell, J. R., Studt, F. E., etc., "Tanganyika Concessions Ltd.," various reports, 1900–1906. Guillemain, C., *Zeitschrift für praktische Geol.,* XXI., p. 334, 1913. Studt, F. E., *Trans. Geol. Soc. of S. Africa,* Vol. XII., p. 166–67, 1909; Vol. XVI., 1913, Johannesburg, 1913.

stone. It is said to be 1,200 feet long, with a width averaging 8 feet, and varying from 3 to 20 feet. The walls are sandstone, though at the surface uphill from the deposit is a band of limonite-cemented conglomerate. The values, which are patchy, are said to average $17 per ton, in gold, silver, platinum and palladium. The relative amounts present are indicated by the following average reported content per cubic meter of a considerable quantity of ore: gold 12.29 grams; platinum and palladium 3.43; silver 8.27 grams. The metals occur for the most part in microscopic particles, but upon washing crushed rock grains of both gold and platinum and globules of gold 1 millimeter in diameter are seen. More or less iron, cobalt, nickel, lead, and copper are associated, the last two occurring as the vanadates, psittacinite and vanadinite, and cupriferous descloizite,[1] while pyromorphite and malachite also occur. These minerals form the "green concentrates," which are a good value indicator. Platinum, palladium, and silver values increase and decrease together, but gold is independent of the others. The platinum and especially the palladium content increase with depth.

Immediately downhill from the outcropping ore body the detrital material contains nuggets of gold, some of which are two inches in diameter, and weigh up to 300 grams. The gold occurs as wire gold, as smooth surfaced nuggets, or as very irregular nuggets, some of which show imprints of other minerals (probably the casts of pyrite, hematite and calcite). The nuggets contain no platinum, and gold is to silver as 200 to 1; the vein bullion on the other hand, according to Buttgenbach, consists by weight of gold 32.77 per cent., silver 25.05 per cent., platinum 36.11 per cent., and palladium 6.06 per cent. Platinum nuggets are rare, but small grains in instances are attached to the gold nuggets, and platinum is sometimes surrounded by gold. Buttgenbach[2] states that in the same detrital deposit a few grains of native tin were found upon a gold nugget. It may be mentioned

[1] Buttgenbach, *Ann. de la Soc. Geol. de Belge*, Pub. Rel. au Congo Belge, Ann., 1911–1912, Annex au Tome XXXIX., pp. 112–16, Liege, 1913. Crystallographic study.

[2] Buttgenbach, *Bull. de la Soc. Belge, Etudes Coloniales*, September–October, 1913, p. 670.

that at the well-known occurrence of native tin on the Clarence River near Oban, New South Wales, the tin is associated with platinum, iridosmine, gold, cassiterite and corundum, a somewhat similar paragenesis.

Studt believes the Ruwe gold deposit to be the gossan of a vein of Devonian age, which was formed by magmatic hot waters derived from what he considers igneous dikes now represented by ferruginous clay. Buttgenbach, on the contrary, believes the ore body to be a fossil beach placer. He is of the opinion that the containing beds are of Kundelungu age (Permian), unlike most geologists who have examined the deposit. Guillemain[1] agrees with Buttgenbach as to the origin of the deposit. So similar is this deposit to the neighboring Katanga copper deposit (indeed sandstone in the vicinity is stained by malachite), that both must be of common orgiin. Both Studt and Buttgenbach hold that the gold of the detrital deposit was dissolved from the ore-body and deposited in place in the detrital material. This belief in the surficial formation of the larger nuggets is based, first, on the absence in the ore body of fair-sized masses of gold; second, on the almost complete absence of platinum in the detrital material and its presence in the ore body; and third, on the form of some of the nuggets, which resemble in instances that of organic remains.

That some solution and redeposition has taken place is evident since Studt[2] states that holes sunk in a swamp below the lode disclosed a peaty clay containing thin films of metallic copper; the copper salt having evidently been leached from the rocks of the mine and reduced to metallic form probably by organic matter.

A similar deposit is said to have been found at Musonoi in beds folded into a syncline. The ore carries up to 8.4 grams gold and 8.6 grams platinum.

Placers.—Placer gold is widely distributed in those portions of the colony underlaid by the pre-Cambrian and Paleozoic rocks,

[1] *Zeitschrift für prak. Geol.*, Vol. XXI., 1913, pp. 334–35.

[2] *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., 1913, Johannesburg, p. 66.

particularly the first, and is even present as sparsely scattered grains in the Jura-Triassic sandstones of the central basin. The placers now being exploited all lie in the northeastern part of the colony, although small placers occur in the Katanga region. The former placers all occur in a region of ancient rocks which have been deeply eroded. The placer deposits (all of which belong to modern streams) may be divided into the following classes:

I. Those derived from quartz lenses or veins in a dioritic country rock,

II. Those closely connected with hematite- and magnetite-bearing metamorphic sedimentary rocks, resembling the Brazilian itabarite,

III. Those derived from the erosion of the outcrops of copper deposits, and,

IV. Those derived by the breakdown of auriferous pyrite and chalcopyrite in diabase.

I. Diorite Country Rock.—Kilo, the most important placer of the colony, is situated in the northeastern part of the colony. As described by Buttgenbach,[1] in the rugged country around Kilo heavy forests fringe the valleys, but on the higher points only grass and bamboo grow. The "bottom," a greenish homogeneous plastic clay, streaked with white, is merely the diorite country rock decomposed. Gold occurs in the top four, rarely eight, inches thereof, and immediately on it, is considerable concentration. The pay dirt consists of sands and somewhat rounded pebbles usually one inch, although in instances eighteen inches, in diameter. The majority of the pebbles are diorite and quartz (some of it containing tourmaline), but others are granite and chlorite- and talc-schists. Some of the quartz pebbles contain cavities partially filled with limonite and gold, pseudomorphs after auriferous pyrite. Both overburden and pay streak vary much in thickness, reaching a maximum of 4¾ feet and averaging about 1⅓ feet. The gold occurring in grains and nuggets, which are frequently thin, is widely distributed in the streams

[1] Buttgengach, *Annales de la Soc. Geol. de Belg.*, XXXVI., Bul., pp. 79-86, 1909, Liege; "Mouvement Geographique," August 24, 1913. Anonymous, "Echo de la Bourse," November 10, 11, 12, 1913.

over a considerable area, but the values are variable; they range from $.45 or less to $37 per cubic yard. The bullion is worth about $18 per ounce, silver being the chief impurity. Between $6,000,000 and $7,000,000 worth of gravel is said to have been blocked out.

Presumably the gold is derived from pyritiferous quartz veins or stringers, probably particularly numerous at the contact of the diorite and granite, as the values decrease rapidly where the streams pass from diorite to granite, and within a short distance thereafter these stop. Up to the time of Buttgenbach's investigations, however, no payable lode had been found, and to date although rumors of rich quartz finds are common, none have as yet been confirmed. Buttgenbach found also as float a quartz conglomerate showing free gold. Gold bearing veins are also reported to occur in the basin of the Nizi river nearby.

II. Associated with Itabarite-like Rocks.—In Brazil, South Carolina and in several South African[1] districts gold ores occur in or are closely associated with banded quartzites or siliceous schists, rich in hematite or magnetite.

The Kanwa mine, situated on the headwaters of the Tele river, is a placer of this type. The region is a heavily wooded, sharply dissected plateau, formed principally of a gneiss-schist complex (Fig. 141). This complex is cut by sparse apophyses of a granite body which covers a large area to the north. Within the complex is a wide band of quartzite (possibly originally somewhat calcareous), which is in large part replaced by hematite.

Quartz stringers and lenticular masses occur frequently within the area, carrying some native gold in slugs up to a weight of three grams. The placers are present day stream gravels, local enrichments generally occurring near quartz outcrops. The better gold values in the streams also seem to have a preference for the vicinity of the iron ore band and for the gneiss-schist contact (Fig. 142). There appears to be no relation between the mineralization of the region and the granite intrusion; indeed, the granite area to the north is sterile.

[1] Ball, S. H., *Mining and Scientific Press*, April, 1913, pp. 578–79.

The nearby state placer of Nebula (really a continuation of the Kanwa deposit) is similar. Important bodies of hematitic quartzite also occur at the Babeyru placer and good shows of gold can be obtained from most of the streams in the vicinity of such siliceous iron ore bodies elsewhere in this portion of the colony. At Moto, situated 325 miles northeast of Stanleyville, the country rock is reported to be granite, diorite and hematite

FIG. 141. Showing heavy verdure, Kanwa goldfield. (Photo. by Claude Brown.)

schists. The pay streams as at Kilo are said to become impoverished as they pass from diorite to granite. The gold is of good quality and the grains as a rule rather fine; large nuggets are rare. Recently, to the southwest of Moto placers have been found along the Kibali and its tributaries, Lemba, Kadi and Kira, and where the Aru and Aho rivers unite to form the Kibali.

Studt,[1] discussing the Katanga iron ores, says: "The gold is sometimes developed along with these iron deposits, but too poor to be economically worked."

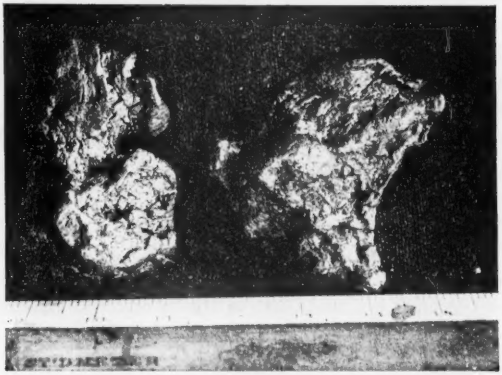


FIG. 142. Well-rounded nuggets, Kanwa.

III. Derived from the Disintegration of the Outcrop of Copper Deposits.[2]—Most Katanga copper ore carries a small gold (traces to 3 grams per ton) and somewhat larger silver (average 42 grams; maximum 72 grams, per ton) content, although only in rare instances does it appear to be enough to warrant separation. Buttgenbach states that the carbonate ore of the Sikasi mine carrying 22.16 per cent. copper, contains 0.781 grams of gold and 31.136 grams of silver or (with silver at $.60 an ounce) $1.04 in precious metals per ton. Among the copper ores this is one of the higher

[1] *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., 1913, Johannesburg, p. 10.

[2] Ball, S. H., and Shaler, M. K., *T. A. I. M. E.*, Vol. XLI., pp. 259–60, 1910. Buttgenbach, "Mouvement Geographique," November 30, 1902, No. 48, columns 585–88; *Bull. de la Soc. Belg. de Geol.*, Tome XVIII., Bruxelles, 1904, Mem., pp. 173–86; *Annales de la Soc. Geol. de Belg.*, Tome XXXIII., Mem., pp. 51–70, Liege, 1905–1906; *Revue Universelle des Mines de la Métallurgie des Travaux publics*, etc., 4th Serie, Vol. XIV., pp. 114–47, 1906; *Annales du Musée du Congo*, 2d Serie, Vol. I., pp. 57–69, 1908, Bruxelles. Farrell, J. R., Studt, F. E., etc., "Tanganyika Concessions Ltd.," various reports, 1900–1906.

in precious metal content. Gold and silver do not appear to increase or decrease with the varying copper content. The matte of the Star of the Congo mine, now being worked, however, carries no appreciable precious metal values. By the erosion of the gold concentrated in the outcrops small placers are developed in streams heading in the copper deposits of Kambove, Likasi, Katanga Musonoi, and Fungurume. At the placers named, in addition to the rough gold the following minerals, characteristic of the copper deposits, are found: malachite, magnetite and hematite, the latter being particularly abundant. Abundant malachite usually accompanies good values. The largest nugget found at the Kambove placer where some of the gravel is very rich weighed about an ounce. After present day torrential rains fresh additions of gold are being made to several of the placers mentioned. Gold also occurs in detrital deposits on slopes below the copper outcrop.

Derived from Pyritiferous Basic Igneous Rocks.—In the lower Congo Brien[1] found gold in certain streams, the clayey alluvium of which was derived from diabase. This rock contains disseminated crystals of pyrite and chalcopyrite and some few of galena. Upon analyses the rock contained a little silver, and traces of gold and platinum were also reported. A geologic map of this region recently completed by us shows that gold deposits of possible future value are confined to a belt in which basic igneous intrusions are particularly abundant.

Tin.[2]—Although cassiterite occurs in several other regions in

[1] Brien, V., *Annales de la Soc. Geol. de Belg.*, Liege, Tome XXXVII., Mem., pp. 71–72, 1909–1910.

[2] Adams, etc., various reports of the Tanganyika Concessions Ltd. Co., 1900–1906. Ball and Shaler, *Trans. A. I. M. E.*, Vol. XLI., pp. 209–10, 1911, New York. Buttgenbach, *Annales de la Soc. Geol. de Belg.*, Vol. XXXIII., Mem., pp. 49–52, 1905–1906; *Annales du Musée au Congo*, 2d Ser., Tome I., pp. 70–72, 1908; *Annales de la Soc. Geol. de Belg.*, Pub. Rel. au Congo Belge, Annex au Tome XL., p. 37, crystallographic study; same annex to Tome XXXIX., fas. III., 1913, pp. 90–104; also crystallographic. Guillemain, *Zeitschrift für praktische Geologie*, 1913, pp. 335–36. Gwyn-Williams, R. H., *Mining Journal*, London, August 23, 1913, pp. 817–18. Studt, F. E., *Annales du Musée du Congo*, 2d Serie, Vol. I., p. 14, 1908; *Trans. of Geol. Soc. of S. Africa*, Vol. XVI., 1913, pp. 54–70. Personal observations.

the Belgian Congo, it is only in the Katanga that deposits which promise to be of commercial value have been found to date.

In the Katanga the northwest face of the rugged plateau, called Monts Mitumba, for a distance of about 250 miles appears to be a tin belt of future possibilities. These mountains are composed of mica schist, tourmaline-bearing quartzites and slates presumably of pre-Cambrian or Cambrian age (Busangà and N'zila series). They are intensely intruded by biotite granites and pegmatites, and are capped by the Kundelungu red sandstone (Permian).

The tin belt strikes N.E. to S.W., parallel to one of Cornet's Louallabien folds. The limits of the belt appear on the south to be a point a short distance north of Ruwe and on the north, Muika. The Union Minière du Haut Katanga has tin holdings for 175 miles along the southern portion of the belt: to the north thereof is an extension owned by the Thys-Jadot group, while still further north along the strike and in similar rocks is Muika a new discovery near Kiambi on the Luvua river.

In the southern portion of the belt the tin deposits are of three kinds: (1) quartz-muscovite-cassiterite veins; (2) residual deposits from these; and (3) placers derived directly from 1 and 2. The veins vary from almost pure quartz to rocks which are practically pegmatitic. They for the most part are situated in the metamorphic rocks near the granite, but some are in the granite itself. The veins are vertical and occur in two sets, one quite regular in values striking N.W., and the other at right angles, sometimes richer but less constant than the first named in content. The veins are from 300 to 4,000 ft. long. Cassiterite occurs in good and often very large crystals, imbedded in quartz, and is frequently more abundant near the borders of the veins. Undoubtedly these veins are dependent in origin on the after-effects of the granite intrusion which Studt considers to be of Ordovician age. The residual deposits, most important economically, are derived from the breakdown of these veins. The tin gravel averages 2 feet in thickness and is said to carry a mean tenor of one per cent. of tin within the claims of the Union Minière du Haut Katanga.

The country rock near Muika is biotite schist, coursing northeast and southwest. It is cut by muscovite or biotite granite, and these rocks are intruded by pegmatite consisting of sugary white quartz, pink felspar and muscovite; the last mineral occurring in plates up to one inch in diameter. Specular hematite, tourmaline, arsenopyrite and cassiterite and, according to Guillemain, also topaz, are accessories. Cassiterite occurs in crystals up to one inch in length. Some of the granite is also altered to stanniferous greisens. Near the ore the slates, quartzites and schists carry tourmaline and pyrite. The tin, which appears to be very unevenly distributed, is coarsely crystalline and blackish in color and in part at least is pseudomorphic after felspar. Tin showings are said to have been traced for two miles. Below the lodes and following their course is detrital material probably 40 feet in maximum width. This is as a rule richer than the underlying pegmatite from which it has been derived, due to the concentration of cassiterite and to the simultaneous abstraction of valueless constituents. True tin placers are not very important. The cassiterite of the detrital and placer deposits is naturally less coarse in grain than that of the rocks in place.

Cassiterite also according to Studt[1] is a constituent of quartzose beds of the Kafubu near topaz-bearing greisen in the Luombwa basin in the extreme southeast portion of the Belgian Congo.

Iron.[2]—Iron ores of various grades and of different origins

[1] *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., Johannesburg, 1913, p. 50.

[2] Ball, S. H., and Shaler, M. K., *Trans. A. I. M. E.*, 1910, pp. 274–77; *Ann. de la Soc. Géol. de Belg.*, 1912–1913, pp. 208–13, and pp. 234–36. Buttgenbach, H., *Ann. de la Soc. Géol. de Belg.*, Pub. Rel. au Congo Belge, Tome XL., p. 5; *Bul. de la Soc. Belge d'Etudes Coloniales*, No. 2, Bruxelles, 1908; *Revue Universelle des Mines de la Métallurgie des Travaux publics*, etc., 4th Serie, Tome 14, p. 114, Bruxelles, 1906. Brien, V., *Annales de la Soc. Géol. de Belg.*, Tome XXXVII., Mem., 254 and 303. Cornet, J., *Mem. et pub. de la Soc. de Sciences Arts et Lettres du Hainant*, Tome IX., 6th Serie, p. 17; *Annales de la Soc. Géol. de Belg.*, Tome XXIV., Mem., pp. 25–190; "World's Iron Ore Resources," Inter. Geol. Congress, Stockholm, 1911, Vol. II., pp. 1035–42; *Bull. de la Soc. Bélg. de Géol.*, Bruxelles, Tome XVII., 1903, pp. 35–44. Guillemain, *Zeitschrift für praktische Geol.*, Vol. XXI., 1913, pp. 330–33. Kostka, R., *Ann. de la Soc. Géol. de Belg.*, Pub. Rel. au Congo Belge,

are widely distributed in the Belgian Congo. As, however, iron ores cannot be exploited under the present economic conditions, but little search has been made for them, and data concerning them are meager.

The deposits which are apt to have future commercial value, occur in the older rocks which rim the Congo basin, but the most widely distributed iron ore occurring practically throughout Central Africa, is a recent superficial deposit. These have been rather loosely named laterites, but more properly can be perhaps referred to as recent iron ores,[1] ferruginous sandstones, and ferruginous clays. These rocks are usually associated with one another, grade into one another, and in a broad sense are of one origin. The areal extent of a single deposit is as a rule small; those covering 1,000 square feet being exceptional, while the thickness is not great. They occur as tabular bodies at the surface or at a slight depth below it, and always above the level of ground water. They frequently lie upon clays or other impervious rocks. The purer iron ores are concretions or outcrops of cellular rock, consisting largely of hydrated oxides (limonite largely), with some hematite. These iron ores are largely of Recent age, but their formation extended from Pleistocene time to the present day. They are in part detrital deposits, the more ferruginous relics of rocks which have disappeared and in part chemical deposits laid down by surface waters heavily charged with iron salts upon impervious basements. In some ways they resemble the Cuban ores derived from the alteration of serpentine and even more closely the iron "laterites" of the Guianas. These superficial iron ores furnished the natives with the greater portion of the iron used prior to the advent of the white man, but it is doubtful if under white regime they are of sufficient tonnage and richness to be exploitable.

Of the iron ores of the older rocks those of the Kasai region,

1912–1913, Annex au Tome XL., fas. III., Liege, 1913, p. 137. Studt, F. E., *Trans. Geol. Soc. of S. Africa*, Vol. XVI., p. 70, Johannesburg, 1913. Personal observations.

[1] Ball, S. H., and Shaler, M. K., *Annales de la Soc. Géol. de Belg.*, 1912–1913, pp. 208–13.

Katanga, the Mayiema-Kivu, and the northeastern portion of the Congo, are most important.

The Kasai region[1] consists of flat-lying sandstones and shales (the Lubilache formation of Jura-Triassic age), resting upon a peneplained surface of supposedly pre-Cambrian rocks. The deeper river valleys have cut through this blanket of younger sedimentary rocks, exposing the older formations as inliers, and in addition hills of the latter harder rocks in places protrude from the surrounding sandstones. These presumably were monadnocks upon the peneplain. The predominant older rock within the triangle bounded by the Kasai, Luebo and Lulua rivers, is an iron formation which appears to be one of the older of the pre-Cambrian series. It underlies the sandstones over an area at least from 7 to 12 miles wide from east to west, and 20 miles long from north to south. Similar rocks are encountered 120 miles farther south.

The iron ore formation is a dark gray, brown or red banded rock, closely resembling the banded iron ores of the Vermillion range, Michigan. The bands vary in thickness from mere knife-edges to layers 4 inches wide.. They are composed of dark gray or red fine-grained hematite, sometimes silicious; fine grained quartzose rocks; dark colored silicious rocks, approaching cherts, and blackish slates. Of rarer occurrence are bands of white dolomite (or limestone?) and limonite. The hematite is in instances of the specular variety, and some magnetite is present. By weathering the silicious bands stand out in relief.

Under the microscope the quartz and iron ores, both hematite and magnetite, which are the principal components of the rock, are seen to be segregated in bands. The quartz bodies are elongated parallel to the schistosity. A little chlorite is present in many slides. Some of the hematite is in contemporaneous intergrowth with quartz; some again cuts the latter in veins or replaces a part of the quartz. Quartz in veinlets appears to be of distinctly later origin.

The iron ore formation has a strike of N. 60°–75° E. to S.

[1] Ball, S. H., and Shaler, M. K., *op. cit.*, pp. 234–36.

60°–75° W. and the beds are either vertical or dip sharply to the S.S.E. Within the formation itself contorted strata are common, as are small sharp folds. Slickensides and brecciation indicate that the formation has suffered more or less faulting and quartz has been deposited not only in such cavities, but also in fractures opened up parallel to the bedding. This is without doubt an ancient sedimentary iron formation metamorphosed, and an analogue of the Lake Superior iron ores, of the Vermillion range.

To the east of south of this region between the Lulua and Sankuru rivers Buttgenbach[1] reports the presence of rocks composed of magnetite and garnet, or magnetite alone, which he considers as basic segregations of pyroxenite. Iron ores of direct igneous origin are not as yet, however, known to be of importance in the Congo. Cornet is inclined to consider the magnetite-hematite-pyrite-quartz mass of Mt. Sali (Lower Congo), lying in quartzites and schists, of this origin.

The iron ores of the northeast portion of the colony were first mentioned by Preumont[2] and have since been visited by one of us, and by several of our associates. They form lines of conical hills which extend a little west of north, parallel to the general strike of the ancient (pre-Cambrian?) schists and gneisses, and to the extension of the igneous masses of this portion of the colony. These iron ores consist of dense rather fine-grained hematite with some magnetite, and are often banded, more siliceous bands alternating with purer ore bands. Microscopic study indicates that they are quartzites which have been replaced by iron, or possibly thoroughly recrystallized ferruginous sandstones. Ordinary specimens consist of alternating bands of interlocking grains of iron ore and quartz.

In the mountains of the Manyiema-Kivu region iron ores are comparatively common. Two types predominate, the more im-

[1] Buttgenbach, *Ann. de la Soc. Geol. de Belg.*, Pub. Rel. au Congo Belge, Annex au Tome XL., p. 5, 1912–1913, Liege. Kostka, R., *Ann. de la Soc. Geol. de Belge*, Pub. Rel. au Congo Belge, Annex au Tome XL., fas. III., Liege, 1913, p. 137.

[2] Preumont, *Quarterly Jour. of Geol. Society*, Vol. 61, 1905, pp. 641–46.

portant being replacements of supposedly pre-Cambrian quartzites; the less important being in Paleozoic limestone. The iron ores in the vicinity of Piana Lusangu are of the first type. Being more resistant to erosion than the surrounding granite and Jura-Triassic shales, these iron ores stand up as conical peaks and domical mountains. There are all gradations from light-colored impure quartzite, the rock replaced, to dense fine-grained specular hematite with some magnetite. The ore is cut by veins of hematite and others of quartz and both minerals line breccia cavities. The introduction of the iron is believed to have been an after effect of the intrusion of the granite magma, as the orebodies are particularly common upon the borders of granitic masses. Further, in this region there appear to be all gradations from specular hematite veins through quartz hematite veins to pegmatites. Similar quartz hematite veins of considerable size are common in many of those portions of the colony underlain by the ancient rocks.

At Muana Kusu in the same general region, 18 miles east-northeast of Kasongo, is a group of hills of probably Paleozoic rocks. Limestone lies upon quartzite conformably. Both rocks have been replaced over small areas by hematite, and that mineral occurs as the filling of fissure veins and in joint fractures and breccia vugs. Limonite and some siderite are associated.

The majority of the iron ore deposits of the Katanga which, according to Cornet,[1] are of large tonnage, occur in a belt to the south of the copper deposits. They consist of hematite and magnetite which are altered to limonite near the surface and along planes of free water circulation. The more important masses lie in disturbed metamorphosed sedimentary rocks which he considers of pre-Cambrian age, including schists, slate, quartzite, halleflinta, dolomite, limestone, chert and jasper. Studt, on the other hand, states that many of the iron ore bodies occur in the Kambove beds. Magnetite and hematite impregnate these beds, form thin beds or large lenses therein, or cut them as vein-

[1] Cornet, *Revue Universelle des Mines de la Métallurgie des Travaux publics*, 1894; "World's Iron Ore Resources," Stockholm, 1910, Vol. II., pp. 1037–42.

lets or veins. The ore of some of the masses is banded. The larger deposits as a rule parallel the stratification of the sedimentary beds, although in instances they cut it. They are usually harder than the surrounding rocks and in consequence protrude as conical hills. The iron ore frequently weathers as huge blocks and the natives live in the crannies between them, shutting the opening with a straw door. Quartz is often associated with the ore bodies, and veins of quartz and hematite or magnetite are common. From such veins the iron minerals in instances impregnate the country rock. This suggests to us that the iron lenses are in part at least replacements of the sedimentary rocks, the solutions having ascended along the fractures now represented by the quartz-hematite veins. Cornet, however, believes most of them to be metamorphosed sedimentary iron ores (originally beds of limonite or siderite) and Guillemain ascribes a sedimentary origin to all of the important bodies. Studt,[1] on the other hand, believes them to have originated through a granite intrusion of mid-Devonian age. In the same region Guillemain describes as unimportant, iron occurrences, gossans, metamorphosed replacements of red hematite in limestone, and unmetamorphosed bedded hematite deposits in the gently folded Kundelungu rocks, the iron minerals being of sedimentary origin. Cornet mentions the presence of abundant hematite and magnetite pebbles and sands in numerous streams in the Katanga region. In the Lukuga coal basin thin beds of iron carbonate occur with the coal.

Miscellaneous Metals.—Platinum and palladium occur in the lode, and platinum in the detrital deposit at Ruwe placer. Platinum has been determined chemically, it is stated, from the concentrates of some of the streams of the lower Congo.

A little native silver occurs associated with the copper ores at Bamanga and also at Mindouli, just over the border in French Congo. The galena of the copper quartz vein at Kitalla, lower Katanga, is reported to be slightly argentiferous (see page 632).

To date no important deposits of zinc and lead are known.

[1] Studt, *Ann. du Musée du Congo,* Ser. II., Tome I., p. 15.

Their ores occur sparingly with the copper of the French Congo, and lead was there smelted by the natives. Thin veinlets of quartz containing galena occur at three localities in amphibolite along the railroad in the lower Congo, and with barite in diabase farther north in the same portion of the colony at Dimba. A little galena has also been found in limestone to the east of the Lulua river about 7° S., and small cupriferous lead veins in the Lubudi limestone (presumably Lower Carboniferous) at Mutambo in the lower Katanga. A little pyromorphite is reported in thin veinlets in the granite at Pambwe, Katanga, by Tréfois. Zincblende occurs with amethystine quartz and siderite at Kongolo on the upper Congo.

Manganese ores have been found in the Katanga, where they are frequently associated with the iron deposits, and in other portions of the colony, but the value of these to date is unproven. Guillemain[1] believes a rather large deposit in the valley of the Fungwe river to be a contact deposit, of perhaps a magmatic segregation, although Delhaye considers it to be a vein. This consists of lenses of high grade manganese ore and quartz at the contact of biotite granite and norite with an older muscovite granite. Tungsten is reported from the granite region of Mulango, and traces of tungsten minerals occur with the tin at Kiambi. Claims for antimony, arsenic and bismuth have been staked in the Katanga.

The widespread presence of recent limonitic ores of detrital and chemical origin in the colony has already been noted. Certain similar deposits contain a large percentage of aluminum, and some are in fact impure pisolitic bauxites.

Diamonds.—The occurrence of diamonds within the Belgian Congo[2] has recently been described by one of us. To date diamonds have been found in three regions, namely, the Kasai region, the Katanga, and the northeastern part of the colony.

[1] Guillemain, C., *Zeitschrift für praktische Geologie*, 1913, pp. 320–37; Cornet, J., "Le Katanga Province Belge," Bruxelles, 1911, p. 84. Studt, F. E., *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., Johannesburg, 1913, p. 70.

[2] Ball, S. H., *Eng. and Min. Jour.*, February 3, 1912, p. 268.

Of the various diamond occurrences in the Congo the alluvial diamond deposits of the Kasai river[1] region (see page 644 for general geology of region) is of large extent, and promises to be of greatest commercial importance. The known diamond bearing area, triangular in form, is 130 miles from north to south, and 65 miles wide at its southern base on the Angola frontier. It includes the drainage of a part of the Kasai river, and its trib-

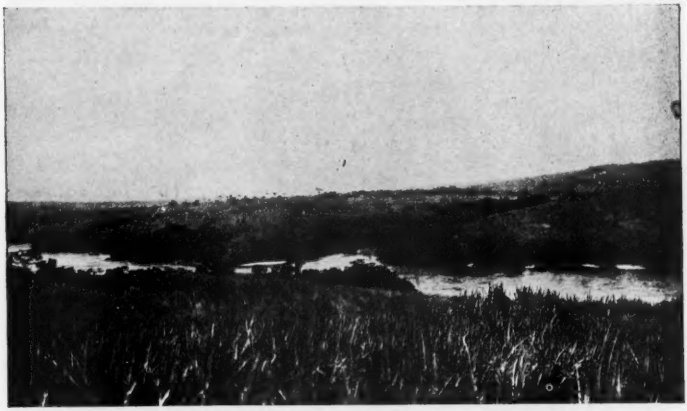


FIG. 143. Junction of Kasai and Tshikapa rivers. Kasai diamond fields. (Photo. by C. Boise.)

utaries from the west, the most important of which are the Lovua, the Tshikapa, the Longatchimo, the Tshipumbu and Lubembe. The diamond field is the property of the Société Internationale Forestière et Minière du Congo, a Belgian-American corporation. The first diamond was found in 1907, but owing to the rather hostile attitude of certain native tribes in the the general region, work, temporarily suspended, was not resumed until the summer of 1911. Exploitation on a small scale began in June, 1913.

[1] S. H. Ball, *op. cited.* Cornet, J., *Ann. de la Soc. Geol. de Belg.*, Pub. Rel. au Congo Belge, 1911–12, Annex au Tome XXXIX., fas. III., pp. 73–76, Liege, 1913. Personal observations. Reports by Oliver, R. B., Boise, Chas., Doyle, D., etc.

The stones occur in (1) Present river gravels, particularly where concentration has been great, namely, in certain of the smaller streams in riffles and pot-holes and gravel bars (Fig.

FIG. 144. Low water on upper Kasai River near mouth of Tshikapa. Kasai diamond fields. (Photo. by R. B. Oliver.)

145) of the larger streams, and (2) Terrace or Bench gravels. (Fig. 146, Fig. 147.) Some of the well-defined terrace deposits occur at least 65 feet above the stream level. The main difference between the gravels of the present stream-beds and those of the terrace gravels is one of cementation. In the latter slight cementation by iron oxides or silica is not uncommon and in places the gravels have been cemented into a conglomerate. The maximum depth of pay gravel is about 20 feet in the terrace gravels and the pay may or may not be covered by a considerable thickness of overburden of sand, sandy clay or silt. In the terrace gravels commercial quantities of diamonds are confined to certain "pay channels." There are also isolated areas of a much more ancient terrace several hundred feet above the present stream beds, and this is known to be diamondiferous.

There is further as one of the topmost members of the Lubi-

lache formation, a conglomerate bed or horizon of conglomerate lenses throughout the region which is from 160 to 390 feet above

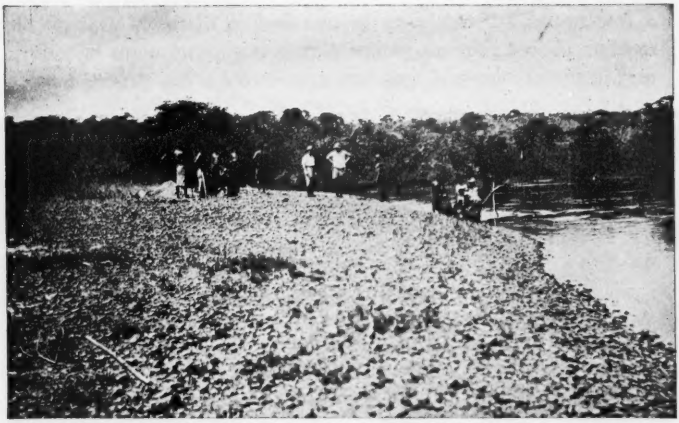


FIG. 145. Diamondiferous gravel bar, Kasai River. (Photo. by Donald Steel.)

the base of the sandstone. The conglomerate bed is in places cemented into a fairly hard rock by limonite, hematite, or silica, although elsewhere it is little more than a gravel bed. The peb-

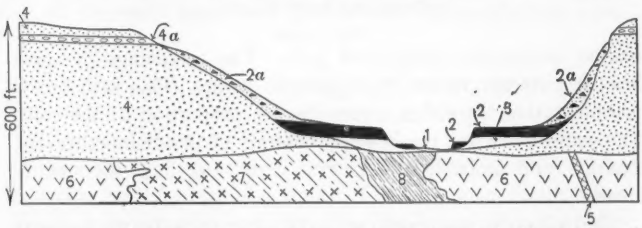


FIG. 146. Diagrammatic cross section of larger streams in Kasai diamond field. 1, Present river gravels, diamondiferous; 2, overburden of lower and upper terraces; 2a, talus overburden, usually highly ferruginous (diamondiferous?); 3, diamondiferous gravels of lower and upper terraces; 4, Lubilache sandstone; 4a, conglomerate bed in Lubilache sandstone (diamondiferous?); 5, diabase dike; 6, granite; 7, granite gneiss; 8, schist; 6, 7 and 8, presumably pre-Cambrian. Adapted from report of C. W. Boise.

bles composing it, which lie in a sand matrix, are well-rounded and are from one fourth to three inches in diameter. They consist of milky quartz, agate, chalcedony and flint. There are also a few rounded boulders up to two feet in diameter of highly metamorphosed siliceous sedimentary rocks. It contains in addition to the pebbles and boulders, grains of quartz, garnet, tour-

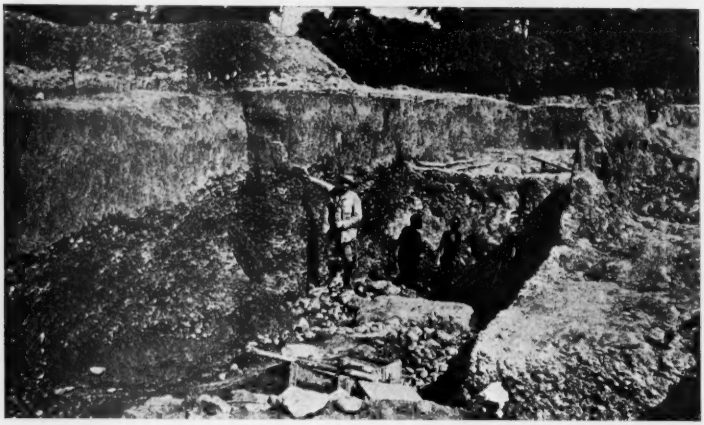


FIG. 147 Pay and overburden, Tshikapa deposit. Kasai diamond fields. (Photo. by Charles Boise.)

maline, magnetite, cyanite and gold. The percentage of these heavier minerals varies from point to point. This bed, by its distintegration, furnishes a considerable proportion of the well-rounded gravels and the heavier minerals of the diamondiferous deposits, and probably at least this conglomerate is diamondiferous.

The minerals associated with the diamonds in the present stream and terrace gravels include quartz, amethyst, opaline quartz, opal, cyanite, zircon, beryl, tourmaline, gold, magnetite, ilmenite, felspar, mica, epidote, hematite, rutile, chrysoberyl and red and white garnets. There are also well-rounded pebbles of carnelian, chalcedony, agate, jasper and chert, and diorite,

schist, sandstone, and granite pebbles; the latter are the rocks of which the country upstream consists. Where the gravels contain a large proportion of well-rounded pebbles of agate, chalcedony and chert, and where tourmaline, garnet, cyanite and the iron ores are relatively abundant, the diamond content is high. The diamond distribution is erratic, but there is a distinct enrichment just above bedrock and where the bedrock is soft (for example, altered granite or gneiss) the diamonds penetrate it for several inches. On the average the greater the percentage of

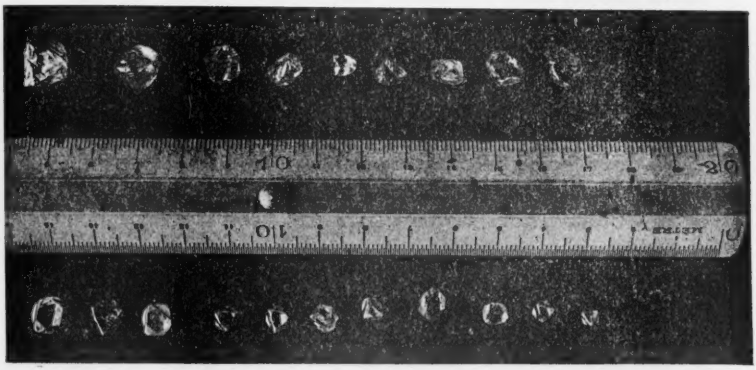


FIG. 148. Diamonds from Kasai diamond field. (The scale is a double decimeter one.)

heavy concentrates present the larger is the average size of the diamonds.

The crystal character of the stones (Fig. 148) and some of the associated minerals are rather of Brazilian affinities. The diamonds are of about the water of the German South West African stones, but on the whole are somewhat smaller. Probably one tenth carat is the average weight of the stones, the largest stone found to date weighing a little less than 15 carats. A considerable percentage of the diamonds are water-white, while the rest are in part yellow and off-color stones, and in part deep yellows, topaz and apple-green stones, fit for fancy gems. Octa-

hedrons predominate, though dodecahedrons are unusually common, and cubes, tetrahexahedrons and trisoctahedrons occur. Determinations of the more complex forms have not as yet been made. The octahedral faces are frequently curved or show triangular etchings, usually elevations. Interpenetration twins with the octahedral faces, the twinning plane, are common and others occur after the Spinel law.

The stones are not derived from the local pre-Cambrian rocks which, where some of the streams have eroded through the Lubilache blanket, occur as inliers. This is shown by the fact that diamonds are found in sandstone country at elevations much greater than those of the most elevated pre-Cambrian exposures. The diamonds as noted above probably occur as pebbles in Jura-Triassic rocks, and if this be true they are presumably of earlier origin than the South African stones, which occur in kimberlite pipes cutting rocks of similar age. The original source of the diamonds, which as yet is unknown, is believed to lie to the south.

In the Katanga diamonds were first discovered in 1906, and to date have been found in the gravels of a creek or creeks of the Mandoko region, near the Rhodesian border, and also in those of Mutendola Creek, a tributary of the Lualaba, and in that river itself, above the rapids of Ngila. The known diamondiferous stretch of the Lualaba includes the bed of that stream and the lower reaches of its tributaries from 9° 30′ to 10° 30′ S. latitude, a distance of 82 miles roughly. At Mutendola creek[1] and in the Lualaba river nearby, some 20 stones were found, the largest weighing 0.28 carats. H. Buttgenbach[2] reports that the form of but few of these stones is determinable crystallographically, but that among the perfect crystals octahedrons and dodecahedrons predominate. Twins are common, and the crystal faces are frequently curved. About one half the stones are colorless, others yellow, brown, and rose, and opaque stones also are mentioned. Studt is inclined to believe that the diamonds of Mutendola creek and the Lualaba river are derived from the break-

[1] Cornet, J., "Le Katanga Province Belge," Bruxelles, 1911, p. 86.

[2] Buttgenbach, H., "Description des Mineraux du Congo Belge," *Ann. du Musée du Congo Belge*, Bruxelles, 1910, pp. 5–10.

down of dioritic or diabasic intrusives, and Cornet suggests their source may be an amygdaloidal diabase.

About 125 miles east of Mutendola creek and to the south and southwest of Lake Moero,[1] some 40 pipes of a basic igneous rock rather similar to kimberlite, the rock in which the South African stones occur, cut the Kundelungu (presumably Permian) red sandstones which are horizontal or dip gently. These sandstones are probably the equivalent of the Karroo beds cut in South Africa by diamondiferous pipes, and broadly, the two sets of intrusives being presumably of an age, the diamonds of the two regions are probably contemporaneous. These pipes of circular or oval plan occur, at least certain of them, according to Studt, along a line parallel to a normal fault of north and south extension, with which they are genetically related. The finding of diamonds in the streams in the general region centered attention upon them, and during 1912 the largest pipe, named Luanza, was prospected by the Kundelungu-Lualaba Company. A number of small stones (some 150), about equal in water to those of German Southwest Africa, were found in 1912. In 1913 it is said that some 30–40 diamonds were recovered per month by washing from 250–380 cubic yards. The stones are said to average about one sixth carat each, the largest stone found to date weighing 3½ carats. A number of these diamonds were exhibited in the Colonial section of the Ghent Exposition in 1913. Work on a second pipe is soon to be started. The surface of the Luanza pipe is merely covered by grass in strong contrast to and in sharp contact with the enclosing scrubbily forested Kundelungu soil with its numerous flowers (Fig. 149); others, however, are not so marked. Structurally the pipes from D'Andrimont's description and figures are quite similar to the South African diamond pipes, and are as a rule several hundred yards in diameter. The largest of these pipes has an area of about 45 acres; the average of some 10 pipes being 9 acres. The Luanza

[1] D'Andrimont, *Soc. Géol. de Belg. Bull.*, XL., pp. 100–13, December 15, 1912. Buttgenbach, *Ann. Soc. Géol. de Belg. Bull.*, XXXVI., Bul., pp. 77–79, Liege, 1908–9. Studt's report to Tanganyika Concessions Company, September 20, 1910. Personal observations.

pipe is oval in plan, its dimentions being about 300 meters by 500 meters (Fig. 150). In addition to small rock inclusions brought up from below, it contains a large mass of sandstone resembling a "floating reef." From the surface down various pits pass through from 3–6½ ft. of clay with quartz pebbles

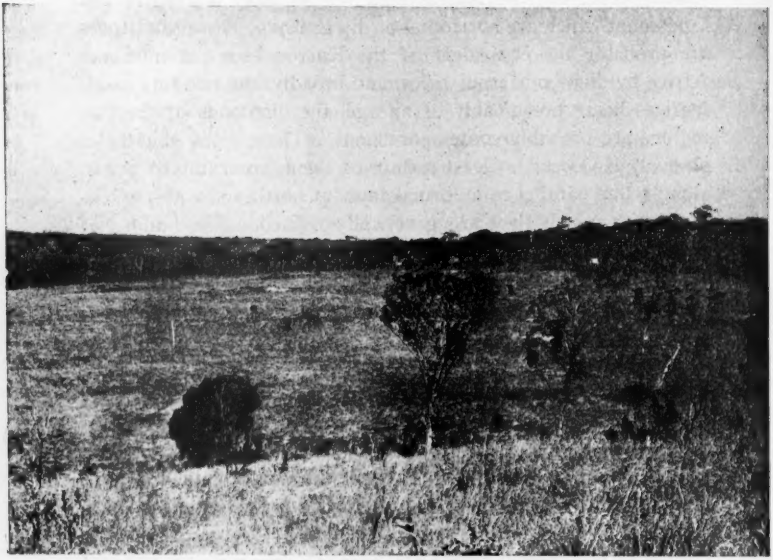


FIG. 149. Luanza pipe, Katanga, showing deforested condition of pipes area.

containing carbonized rootlets, etc., 6–20 ft. of detrital or alluvial clay with many pebbles; at certain points the clay is cemented by iron hydroxides, 6–20 ft. of "yellow ground"; changing into less altered greenish or bluish breccia which extends to the greatest depth yet reached (about 90 ft.). Chalcedonic quartz is common in cavities of the "yellow ground." This change from yellow to blue ground occurs at water-level, which is usually shallow in the area. Studt states that both yellow and blue ground disintegrate upon drying.

In the decomposed "yellow ground" a micaceous mineral (determined by Buttgenbach to be bastite), ilmenite, garnet (almandine or spessatrine, perhaps both), and olivine (more or less serpentinized), are readily distinguished; and in addition chromite, amphibole and quartz, also occur. In it are also rounded masses of Kundelungu shale and sandstone; a schistose calcare-

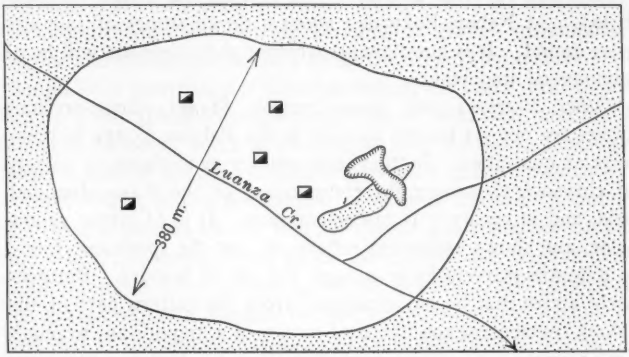


FIG. 150. Plan of Luanza pipe after d'Andrimont.

ous rock, granite, quartzite, felspar crystals, and rolled fragments of quartz. Concentrates consist of garnet, chromite, olivine, quartz and amphibole, and black mica, besides various rock fragments. All of these minerals are found at Kimberley, with the possible exception of amphibole, which may be in reality omphacite, a pyroxene as suggested by Buttgenbach. From the Chilonga pipe Studt reports nodules of eclogite and eulysite, and he adds the following associated minerals: diopside, diallage, wollastonite, phlogopite, chlorite, talc, ilmenite, magnetite, zircon,

aragonite, calcite and goyazite. Apparently rock sufficiently fresh for microscopic examination has not as yet been found in the pipes.

Recently a few diamonds have been found among the concentrates of three and probably five of the gold placers in the northeastern portion of the colony (Kanwa, Babeyru and Nebula-Bokwama, and reported also at Moto, and on the Nizi river near Kilo). At Nebula-Bokwama about a dozen stones of fair size were found. It is questionable whether these deposits will be of commercial importance.

Other Precious and Semi-Precious Stones.—Semi-precious stones are not yet known to exist in the Belgian Congo in commercial quantities. Buttgenbach reports cymophane, a variety of chrysoberyl, among the concentrates of the Kasai diamond field, and in reality it is rather common. It is of citron yellow color, and shows opalescent reflections, but the specimens found to date are scarcely large enough for use in jewelry. Buttgenbach[1] states that he has examined from the eastern part of the colony transparent specimens of zircon of a magnificent hyacinth tint, suitable for jewelry were they larger. He[2] has also seen small specimens of the sapphire variety of corundum from the same region, and violet, opaque, corundum from the Kasai. Corundum has also been found in the Katanga.

Cyanite is abundant in the concentrates from the Kasai diamond fields, and in schists in the northeast portion of the colony; particularly fine specimens coming from the Uelle river between Amadi and Bambili. Mr. C. A. Reid collected from the latter region numerous specimens several inches long and of beautiful seagreen color, which might have a certain value as semi-precious stones. In the same region Schweinfurth in 1870 found the mica schist of Mount Bandupoi to contain many crystals of cyanite from 1 to 2 inches long; these were afterwards described by Liebisch.[3] A Belgian officer, Lieut. R. Dubreucq, in 1895,

[1] Buttgenbach, *Bull. de la Soc. Belg. Etudes Coloniales*, 1913, p. 671.

[2] *Idem*, p. 672.

[3] Cornet, *Bull. de la Soc. Belge de Geol.*, Tome XII., 1898, pp. 26–30. Hintze, "Handbuch der Mineralogie," Bd. II., S. 161. Liebisch, *Zeitschr. d. Geol. Gesellsch.*, 1877, Vol. 29, p. 718.

brought back some crystals over 3 inches long. Semi-precious varieties of quartz are common; rock crystal is found in the Lower Congo; amethyst comes from the Mayiema-Kivu region and elsewhere; agate and chalcedony are widely distributed; and opal, opaline quartz and hyalite also occur. Kostka found veinlets of chrysoprase in basic igneous rocks near the confluence of the Bushimai and Sankuru rivers. Buttgenbach has determined the presence of the following varieties of garnet, grossularite, pyrope and spessartine, as well as andalusite and staurolite. Although black tourmaline is abundant among the older rocks of the colony, gem varieties of commercial size are unknown; needles of rubellite, however, occur in mica schist near Kikondja, Katanga. Beryl is also of course a constituent of some granite pegmatites.

Salt.—Rock salt is not known to exist in the colony, but in the eastern portion of the Belgian Congo are a number of hot and cold saline springs from which the natives have long obtained salt. Many of these springs are situated along faults parallel to the graben of Lake Tanganyika and to the other main faults of that part of the Belgian Congo. At Bena Sombo near Nyangwe[1] rather strongly saline water, with a temperature between 44° and 47° C., bubbles gently from crevices in flat-lying Jura-Triassic shale at the wide head of a valley. An analysis of the water made since our visit shows it to contain 1.15 per cent. of salt.[2] Another spring at times worked by the natives exists a short distance to the northeast. Four or five nearly boiling and more or less intermittent hot springs issue from a point at the extreme north end of Lubware Peninsula (Lake Tanganyika). A liter of this water yields a heaping teaspoonful of fairly pure salt. These springs are presumably connected with the faulting by which the Tanganyika Lake depression was formed.

At Moachia, in the Katanga,[3] is a mineral spring, the tempera-

[1] Ball, S. H., and Shaler, M. K., *T. A. I. M. E.*, Vol. XLI., p. 214, New York City, 1910.

[2] Cornet, J., *Ann de la Soc. Geol. de Belge,* Pub. Rel. au Congo Belge, Annex au Tome XL., des Annales, fas. 2, pp. 103–25, Liege, 1913.

[3] Cornet, J., *Ann. du Musée du Congo,* Series II., Tome I., pp. 87–89. Mathieu, F. F., *Ann. de la Soc. Géol. de Belg.,* Pub. Rel. au Congo Belge, etc., Annex au Tome XL., des Annales, Fas. 2, pp. 103–25, Liege, 1913.

ture of which ranges from 35° to 40° C. The salts in solution are largely sodium chloride and magnesian sulphate. In other portions of the Katanga saline springs, mostly thermal, are quite common.

Coal.—If important deposits of coal occur in the Belgian Congo they will presumably be found in the flat or gently inclined Kundelungu (Permian?) beds, or in the horizontal Jura-Triassic rocks. In October, 1911, the most important coal discovery to date in the colony was made on the Lukuga river near Lake Tanganyika. Transportation will be furnished by the nearby railroad now almost finished, between Lake Tanganyika and the Congo river.[1] The coal-bearing series consists of a basal conglomerate of glacial origin, on which are black shales. Above these beds are sandstones and arkoses with coal intercalated, containing in their upper portion black greasy shale bands. A few bands of iron carbonate are interbedded. This is succeeded by red shales on which lie red shales and a little limestone, and thick red sandstones, in part conglomeratic. The beds are not only lenticular, but are much faulted by the north to south faults so characteristic of the Tanganyika region. Fossils indicate according to Fourmarier that the rocks are of Permo-Triassic age, and are the equivalent of either the Beaufort or Stormberg beds of South Africa, also coal-bearing. Mercenier,[2] on the other hand, believes, from fossil plants collected, that the coal-bearing beds should be correlated rather with the Ecca series of South Africa and Renier, Mercenier and Xhignesse state that it underlies the Kundelungu formation. These gently inclined rocks contain five beds of coal from 2 to 6½ ft. thick, and totalling some 16 ft., which are separated from one another by less than 32 ft. of barren material. The coal has been traced for some 20 miles

[1] Studt, F. E., *Trans. of the Geol. Soc. of S. Africa*, Vol. XVI., pp. 77–80, Johannesburg, 1913. Fourmarier, P., *Ann. de la Soc. Géol. de Belg.*, 1913, pp. 83–84.

[2] Renier, Arm., "Coal Resources of the World," Vol. I., p. lx., International Geol. Congress, Toronto, 1913. Mercenier, A., et M. Xhignesse, *Revue Universelles des Mines*, etc., 5th Serie, Vol. I., pp. 143–48, Pl. V., 1913, Liege. Mercenier, *Ann. de la Soc. Géol. de Belg.*, Pub. Rel. au Congo Belge, 1912–1913, Annex au Tome XL., fas. III., Liege, 1913, pp. 165–74.

and underlies at least 12 square miles. The coal is sub-bituminous, hard and light, and some of it is of brilliant lustre. It resembles some of the poorer Rhodesian coal, containing from 28 to 45 per cent. volatile matter, and 18 to 20 per cent. ash, and having a calorific power of from 6,500 to 7,000 calories. It will presumably be fit for certain industrial purposes. Fourmarier reports other outcrops near Lake Tanganyika, extending north well toward the 5th parallel.

On Luweisha creek,[1] a tributary of the Lualaba in about latitude 9° 45′ S. (Katanga), some seams of very impure coal have been found. These occur in the Lualaba formation (Beaufort of South Africa or, according to Studt, Ecca beds), perhaps at a higher horizon than that of the locality last described, and are associated with black shales and micaceous sandstones. Some of the seams are over a meter thick, but contain much shale, and in addition pyrite is abundant. A little drilling shows two coal bearing horizons stratigraphically 490 feet apart. Two analyses from Luweisha and one from Shina (12 miles south of Luweisha) follow:

	Shina.	Luweisha.	Luweisha.
Volatile matter	16.1	28.98	19.59
Fixed carbon	27.	48.28	30.25
Ash	52.	9.5	39.75
Water at 100°	4.9	10.00	10.41

Gwyn-Williams[2] states that at two places on Katanga Creek, a tributary of the Lumva or Lubumba river near 5° S. latitude (Katanga), carbonaceous shales enclose shaly coal. The bed which is 1½ meters thick, dips N. 70° E. 6°, near its center are two or three thin seams of "anthracite." Lower down the Congo river near Ponthierville a few thin seams of coaly matter have been found at approximately the same horizon.

[1] Buttgenbach, H., *Ann. du Musée du Congo,* Series II., Tome I., Bruxelles, 1908, pp. 73–74. Cornet, J., "Le Katanga Province Belge," Bruxelles, 1911, p. 87. Studt, F. E., *Trans. of the Geol. Soc. of S. Africa,* Vol. XVI., 1913, p. 57.

[2] Gwyn-Williams, *Mining Journal,* August 30, 1913, London, p. 840.

That exploitable coal will be found in the Paleozoic and pre-Cambrian rocks of the rim rock regions, is doubtful, since in at least the latter the metamorphism has been too great. Cornet[1] reports that near the village of Kilasa (Katanga) seamlets several millimeters thick of anthracite, occur in shales of the Kisola series (Wemashi of Studt; presumably Middle Silurian). The rocks here consist of a thick conglomerate with carbonaceous shaly cement; on this lie the coal bearing shales, and on them in turn gray, blue limestone.

Graphitic Schists.—Graphitic schists, metamorphosed sedimentary rocks, supposedly of pre-Cambrian age, occur abundantly in the Manyiema-Kivu region. Brien[2] reports the presence of a number of beds of graphitic schists, carrying a fair per cent. of carbon in the vicinity of Lukula in the lower Congo.

Bituminous Shales and Asphaltic Rock.—Carbonaceous shales, of Jura-Triassic age, occur in the vicinity of Nyangwe on the upper Congo river. In the vicinity of Ponthierville[3] at several localities are thin beds of black bituminous fossiliferous Jura-Triassic shale reaching a maximum thickness of 1½ meters. Upon distillation the rock yields from 70 to 170 liters of oil per ton. Associated with some of the outcrops are thin beds of lignite. A company has drilled for oil without success. Bitumen from time to time is said to be found floating upon the surface of Lake Tanganyika. Bituminous rocks have been reported from a number of points along the Atlantic Coast between Gabun (just south of the equator) and a point south of Saô Paul de Loanda (about 7° S. latitude), Angola. In the vicinity of Shipanga, Belgian Congo, are folded sandstone and cavernous limestone of considerable thickness, representative of these rocks. These rocks are saturated with asphalt, and upon analyses show about 24 per cent. of asphaltic matter. Several small oil seeps head in these rocks. The rocks dip toward the coast and as they are covered by impervious beds, general geological conditions are fav-

[1] Cornet, J., *Bull. de la Soc. Belg. de Géol.*, Tome XVII., 1903, pp. 13–15.
[2] *Ann. de la Soc. Géol. de Belg.*, Tome XXXVII., Mem., p. 249.
[3] Passau, G., *Annales de la Soc. Géol. de Belg.*, Tome XXXVII., Mem., p. 364, Liege, 1910.

orable for finding oil, as suggested by Pechuel-Loesche in the last quarter of the nineteenth century.

Miscellaneous Non-metallic Minerals.—Copal in part fossil, and in part resin from living trees, is bought in considerable quantities by the various commercial companies from the natives. In 1912 its export value was 6,384,865 francs.

Monazite, zircon and anatase have been found in concentrates in gold prospecting. Allanite is fairly abundant in certain pegmatites of monzonitic affinities near Luluabourg. Barite occurs in large residual masses on the lower Congo railroad about halfway between Thysville and Matadi. Apatite, fluorspar, and strontianite, although found in fair quantities, are not exploited.

In the Manyiema-Kivu region graphite is found as a not abundant constituent of pegmatite, and muscovite in good sized books is of similar occurrence in that region. Studt[1] reports an occurrence of asbestos in the Katanga region.

[1] Studt, *Trans. Geol. Soc. of South Africa,* Vol. XII., p. 164.

STUDIES IN SILVER ENRICHMENT.[1]

TETRANICKEL-TRIARSENIDE, ITS CAPACITY AS SILVER PRECIPITANT.

CHASE PALMER.[2]

The precipitation of free silver by the interaction between many metallic minerals and dilute silver sulphate solution has been described in detail by Palmer and Bastin[3] in an introductory chapter of their studies in silver enrichment. Noteworthy among silver precipitants is the nickel monarsenide, niccolite (Nias). Quantitative experiments have shown that, coincident with the deposition of silver, the substance, niccolite, is completely dissolved as nickel sulphate and arsenious acid and that the proportions of the substances involved in the reaction may be expressed by the equation

$$2NiAs + 5Ag_2SO_4 + 3H_2O = 2NiSO_4 + As_2O_3 + 3H_2SO_4 + 10Ag.$$

Thus one gram of niccolite is capable of precipitating 4.02 grams of metallic silver.

Inasmuch as this property of niccolite may have a direct bearing on the origin of rich silver deposits such as are found in the Canadian Cobalt district, where arsenides of cobalt and nickel abound, the study of the precipitation capacities of other arsenides and similar minerals has been undertaken to determine to what extent arsenides and antimonides in general share with niccolite the power to precipitate silver from silver salt solutions. Of the several minerals that have been studied quantitatively

[1] Second communication in a series of geological and chemical coöperative studies by Bastin and Palmer.

[2] Published by permission of the Director of the U. S. Geological Survey.

[3] Palmer, Chase, and Bastin, Edson S., "Metallic Minerals as Precipitants of Silver and Gold," ECONOMIC GEOLOGY, Vol. 8, pp. 140–170, 1913.

with respect to their conduct towards silver solutions one in particular deserves special mention. It was obtained from a well known company of mineral dealers and purported to be chloanthite ($NiAs_2$) from Mansfeld, Thüringen, Germany. The material is light grey with a tinge of red. Weighed quantities of the powdered mineral were digested in dilute silver sulphate solutions. As in the case of niccolite action began promptly, an abundant silver deposit was soon formed, and the solution became green. The results of the experiments recorded below show conclusively that the mineral cannot be chloanthite ($NiAs_2$), nor rammelsbergite ($NiAs_2$) which it closely resembles, but is a wholly different substance, which, according to the atomic proportions of its soluble constituents, may be called tetranickel-triarsenide (Ni_4As_3).

Experiment 1. Action of the Mineral with an Aqueous Solution Containing a Large Excess of Silver Sulphate.—The finely powdered mineral (0.363 gram) was digested over night in about 750 c.c. of a solution containing 3.8 grams silver sulphate. Silver soon began to deposit in beautiful, white, arborescent crystals. After 12 hours the small amount of dark residue together with the abundant silver deposit was filtered from the green solution. The deposit contained 1.4089 grams metallic silver. After its removal the residue yielded

.0093 gr. Bi_2S_3	= Bi	2.55	per cent.
.0111 gr. $BaSO_4$	= S	.42	per cent.
.0008 gr. Fe_2O_3	= Fe	.15	per cent.
.0034 gr. gangue	=	.93	per cent.

and from the solution were obtained

.1726 gr. Ni	= Ni	47.55	per cent.
.0045 gr. Co	= Co	1.24	per cent.
.2809 gr. A_2S_3	= As	47.05	per cent.
		99.89	per cent.

Atomic proportions of the dissolved constituents:

47.55 ÷ 58.7 = .8101	} .8311	Ni(Co)
1.24 ÷ 59. = .0210		
47.05 ÷ 75. = .6273		As

and

$$.8311 : .6273 = 3.98 : 3 = Ni_4As_3.$$

These results show that the substance dissolved by the silver sulphate solution constitutes 95.84 per cent. of the material under examination, and that the empirical formula, Ni_4As_3, represents the atomic proportions of the constituents of the dissolved mineral.

Ratio of precipitated silver and the mineral (Ni_4As_3). 0.363 gram material contains 0.352 gram Ni_4As_3 (mol. wt. 459.8).

Percentage

$$388.12 \div 107.9 = 3.5970 \text{ Ag},$$
$$95.84 \div 459.8 = 0.2084 \text{ } Ni_4As_3,$$

and $3.5970 : 2084 = 17 : 1$.

Thus tetranickel-triarsenide precipitates silver in the proportion of one molecule to 17 atoms of silver. In other words, one gram of this nickel arsenide has the capacity of depositing 3.99 grams of metallic silver.

Experiment 2. Action of the Mineral with an Aqueous Solution Containing a Deficiency of Silver Sulphate.—The possibility that the material dissolved by silver sulphate solution might be a mixture of normal nickel arsenide (Ni_3As_2) and niccolite (NiAs) in molecular proportions was considered, and to obtain light on this question an experiment in fractional oxidation was tried.

The powdered mineral (.4006 gram) was digested 12 hours in 500 c.c. of a solution containing 1.52 grams silver sulphate. In this time 1.045 grams metallic silver, that is, 260.9 per cent. of the weight of the material used, had been precipitated and 0.2628 gram, that is, 65.6 per cent. of the material, was dissolved, the dissolved constituents being distributed as follows:

Ni(Co),	.1334 gram	= 33.30 per cent.
As,	.1294 gram	= 32.30 per cent.
	.2628 gram	= 65.60 per cent.

Atomic proportions of the dissolved constituents:

Percentage

$33.30 \div 58.7 = .5683$ Ni(Co),
$32.30 \div 75. = .4306$ As,
$.5683 : .4306 = 3.96 : 3.$

Ratio of precipitated silver and dissolved mineral:

Percentage

$260.9 \div 107.9 = 2.4179$ Ag,
$65.6 \div 459.8 = 0.1431$ Ni_4As_3,

and $2.4179 : .1431 = 16.9 : 1.$

Thus also when the mineral is only partially oxidized four atoms of nickel and three atoms of arsenic enter the solution together and 17 atoms of silver are deposited. Additional evidence, therefore, is obtained that the soluble mineral is a definite substance and not a mixture of two substances.

Prior to these observations which were made in January, 1914, F. Grünling[1] announced the discovery by W. Maucher of a new silver-white nickel arsenide. From the chemical analyses accompanying his description of the mineral Grünling assigned to it the formula for normal nickel arsenide, Ni_3As_2, and he named it *maucherite*. In February, 1914, T. L. Walker[2] reported a new mineral received from the Cobalt district, Ontario. The description of the physical properties of Walker's Ontario mineral closely corresponds to the description of the properties of Grünling's maucherite, but Walker interpreted the analytical results obtained from his mineral as indicative of tetranickel-triarsenide (Ni_4As_3). In view of these two recent observations and of the writer's conclusions concerning the real chemical proportions of nickel and arsenic in the specimen which he received for chloanthite, but which by means of the silver sulphate solution was found to be tetranickel-triarsenide, it seemed desirable

[1] Grünling, F., "Maucherit, ein neues Nickelmineral," *Centralblatt für Mineralogie, Geologie und Paläontologie,* April 15, 1913, p. 225.

[2] Walker, T. L., "Temiskamite, a New Nickel Arsenide from Ontario," *Amer. Jour. Science,* 4th ser., Vol. XXXVII., p. 170.

to make a comparative study of all three substances. In response to requests Professor Grünling and Professor Walker generously contributed supplies of their minerals so that this work could be done.

Experiment 3, with Maucherite, Grünling's Mineral from Eisleben, Thüringen.—Silver-white grains of maucherite were carefully selected, finely ground, and the heavy material was separated from gangue by methylene iodide. The mineral (.3992 gram) was digested over night in 750 c.c. of an aqueous solution containing 3.12 grams silver sulphate. 1.5702 grams silver was deposited—equivalent to 393.3 per cent. of the weight of the material taken.

The residue also yielded

	.05 per cent.	S
	.27 per cent.	Bi
	.04 per cent.	Fe
	.81 per cent.	gangue

and from the solution were obtained

.1942 gram Ni	= 48.80 per cent.	Ni,
.0052 gram Co	= 1.32 per cent.	Co,
.3172 gram As_2S_3	= 48.50 per cent.	As,
	99.79	

The atomic ratios of the dissolved constituents are

Percentage.		
48.80 ÷ 58.7 = .8313	Ni	} = .8536 Ni(Co),
1.32 ÷ 59. = .0223	Co	}
48.50 ÷ 75. = .6467	As	
98.62		

and .8536 : .6467 = 3.96 : 3.

From these calculations it is evident that the nickel arsenide, called maucherite, constitutes nearly 99 per cent. of the material under examination and has the empirical formula Ni_4As_3.

Ratio of precipitated silver and Ni_4As_3:

Percentage.	
393.8 ÷ 107.9 = 3.645	Ag,
98.62 ÷ 459.8 = .2144	Ni_4As_3

and 3.645 : .2144 = 17 : 1.

Thus this nickel arsenide has the same capacity for precipitating metallic silver as has the miscalled "chloanthite" which has already been reviewed.

C. Friedrich's analytical results of the chief constituents, as stated by Grünling in his description of the mineral, are Ni 49.51 per cent., Co 0.93 per cent. and As 45.66 per cent. Total 96.10 per cent., of which the atomic ratios are

$$\left.\begin{array}{l} 49.51 \div 58.7 = .8434 \\ 0.93 \div 59. = .0157 \end{array}\right\} .8591 \text{ Ni(Co)},$$
$$45.66 \div 75. = .6088 \text{ As}$$

and $.8591 : .6088 = 423 : 3$.

It thus appears that Friedrich's results conform to the formula Ni_4As_3 about as closely as to the formula Ni_3As_2.

Experiment 4, with Walker's "Temiskamite" from Elk Lake, Ontario.—The material was carefully selected, run through a 100-mesh sieve, and the powder separated as far as possible from gangue by methylene iodide. The weighed mineral was digested for two days with 600 c.c. of a solution containing 2.33 grams silver sulphate.

.4018 gram mineral precipitated
1.4937 grams free silver.

From the residue were also obtained

.0065 gram	Co	= 1.61	per cent. Co,
.0161 gram	$Mg_2As_2O_7$	= 1.94	per cent. As,
.0255 gram	$BaSO_4$	= .87	per cent. S,
.0100 gram	Bi_2S_3	= 1.99	per cent. Bi,
	Gangue	= .64	per cent.

and from the solution were obtained

.1916 gram	Ni	= 47.69	per cent. Ni,
.0017 gram	Co	= .42	per cent. Co,
.2951 gram	As_2S_3	= 44.65	per cent. As,
		99.81	

Atomic ratios of the constituents found in the residue:

$$\left.\begin{array}{l} 1.61 \div 59 = .0273 \text{ Co} = 1 \\ 1.94 \div 75 = .0259 \text{ As} = 1 \\ .87 \div 32 = .0271 \text{ S} = 1 \end{array}\right\} \text{CoAsS},$$

and of the dissolved constituents:

$$\left.\begin{array}{l} 47.69 \div 58.7 = .8124 \\ .42 \div 59. = .0007 \end{array}\right\} .8131 \text{ Ni(Co)},$$
$$44.65 \div 75. = .5953 \quad \text{As},$$

and

$$.8131 \div .5953 = 4.11 : 3 = \text{Ni}_4\text{As}_3.$$

This oxidation experiment shows, not only that the chief homogeneous substance in the Canadian product is tetranickel-triarsenide, but also that a substance answering to cobaltite is present in appreciable amount. The bismuth appears to be in the metallic state. From all the analytical data obtained by this experiment the natural product may be considered to be a mixture consisting essentially of

92.76 per cent. tetranickel-triarsenide (Ni_4As_3),
4.42 per cent. cobaltite (CoAsS),
1.99 per cent. bismuth,
.64 per cent. gangue.

99.81

Ratio of the Canadian tetranickel-triarsenide and precipitated silver:

Percentage

$$371.7 \div 107.9 = 3.4448 \text{ Ag},$$
$$92.76 \div 459.8 = .2017 \text{ } \text{Ni}_4\text{As}_3$$

and

$$3.4448 : .2017 = 17.08 : 1 = 17\text{Ag} : \text{Ni}_4\text{As}_3.$$

This experiment also shows that one gram of tetranickel-triarsenide is capable of precipitating practically four grams of metallic silver.

The silver precipitation capacity of this Canadian product, like that of the miscalled Chloanthiate from Mansfeld and of Gründing's maucherite from Eisleben, depends on the amount of tetranickel-triarsenide contained in it. Since in every instance one molecular weight of the nickel arsenide (Ni_4As_3) is capable of precipitating silver in the weight proportion of 17 atoms, and since the oxidation product is limited to arsenious acid, the proportional amounts of the substances participating in the reaction with silver sulphate solution may be expressed by the following equation:

$$2Ni_4As_3 + 17Ag_2SO_4 + 9H_2O = 8NiSO_4 + 3As_2O_3 + 9H_2SO_4 + 34Ag.$$

A striking feature of all these experiments is the definiteness of the reaction between tetranickel-triarsenide and silver sulphate solution and it recalls the reaction between silver sulphate solution and niccolite which is of the same order of regularity.

Since tetranickel-triarsenide was first observed as a new species by Maucher, it seems appropriate that *Maucherite,* the name given to it by Grünling, be retained.

MAUCHERITE FROM MANSFELD, THÜRINGEN.

Properties.—Cleavage imperfect, fracture uneven, brittle, hardness 5, specific gravity 7.80, luster metallic, color white with red tarnish, streak black, not magnetic, opaque, fusibility 2. Soluble in strong nitric acid with evolution of nitrous fumes. Closed tube, slight deposit of arsenious oxide. Open tube, abundant deposit of arsenious oxide. On charcoal, white arsenic coating. This description of tetranickel-triarsenide from Mansfeld applies equally well to Walker's Canadian specimen and to Grünling's maucherite from Eisleben. Moreover, freshly polished surfaces of all three specimens observed under the reflecting microscope by daylight showed that a radiating fibrous structure is common to all and that all have exactly the same silver gray color. For specific gravity determinations by the standard pyknometer method of the U. S. Geological Survey the writer is

indebted to George Steiger. The determinations were made at 25° C. on the powdered materials as they were used for the experiments described in this paper. For comparison the tabulation is in descending order of maucherite content.

	Grünling's Mineral.	Palmer's Mineral.	Walker's Mineral.
Per cent. Ni_4As_3	98.62	95.84	92.76
Specific gravity.....	7.81	7.80	7.73

CRYSTALLOGRAPHY.

Tetragonal—The three specimens of maucherite used in these experiments are all of the massive variety with nothing indicative of crystalline form. Very recently, however, A. Rosati[1] has reported the results of an exhaustive investigation of the crystallography of Grünling's maucherite, his results being based largely on new material supplied by Maucher himself. According to Rosati maucherite is tetragonal, its usual form being in thin quadratic plates parallel to the base with the other faces strongly striated.

THURINGIAN MAUCHERITE.

In the Mansfeld mining district, Thüringen, not far from Eisleben where Grünling's maucherite was found is the "Sangerhäuser Reviere"[2] long famous for its rich output of nickel ores. In an extensive report on the nickel ores of that district in 1857 Bäumler[3] stated that the prevailing variety of niccolite at Sangerhausen was faintly lustrous and had a touch of grey. This paleness Bäumler ascribed to chloanthite ($NiAs_2$) and cobaltite (CoAsS) mechanically admixed with true niccolite (NiAs). Grunow's[4] analysis of the product does not conform to this view which demands that the ratio of the percentage values of nickel and arsenic should be larger than it is in niccolite, whereas it is

[1] Rosati, A., "Über Maucherit und Placodin," *Zeitsch. für Kryst. und Min.*, Vol. 53 (1914), p. 389.

[2] So-called by Bäumler.

[3] Über das Vorkommen vom Nickelerzen im Mansfeldschen Kupferschiefergebirge," Bäumler, *Zeitsch. d. deutsch. geol. Gesellsch.*, IX., 1857, pp. 25–50.

[4] *Ibid.*, p. 40.

much smaller; in fact, it is the ratio appertaining to tetranickel-triarsenide (Ni_4As_3).

Composition of the Sangerhausen ore according to Grunow.

Ni(Co?),	48.4	per cent.
As,	48.7	per cent.
S,	2.8	per cent.
	99.9	per cent.

In the light of our present knowledge of the occurrence of Grünling's maucherite in the neighboring mines at Eisleben, and Palmer's Mansfeld maucherite it is possible that the faintly lustrous nickel arsenide, considered by Bäumler to be a variety of niccolite, was really tetranickel-triarsenide, that is, maucherite, with mechanically admixed cobalite, or its nickel homologue, and that the pale ore examined by Grunow consisted essentially of 85.4 per cent. maucherite (Ni_4As_3) and 14.5 per cent. cobalite (CoAsS).

From these considerations it may be suspected that tetranickel-triarsenide has formed a not inconsiderable part of the output of the Mansfeld mining district.

In addition to the above described experiments with maucherite,, quantitative oxidation experiments have been made likewise with several arsenical minerals including niccolite (NiAs), smaltite ($CoAS_2$), cobaltite (CoAsS), and arsenopyrite (FeAsS), and a few deductions from these experiments may be stated in a brief summary.

SUMMARY.

1. The mineral, maucherite, tetranickel-triarsenide (Ni_4As_3), containing the largest proportion of nickel of all nickel arsenides known, is a homogeneous substance. It appears to be rather widely distributed, for within one year it has been found on two continents.

2. Silver sulphate solution is an efficient solvent of pure arsenides preparatory to analysis.

3. In sulpharsenides, preferably called arsenosulphides, sulphur appears to functionate atomically with arsenic, the arseno-

sulphide group (AsS) being strongly resistant to the oxidizing action of silver salt solutions. Sulphur, therefore, may be regarded as a protector of arsenic against oxidation by silver salt solutions.

4. In regions abounding in deposits of native silver associated with arsenical minerals the source of the silver should be attributed to the action of arsenides rather than of arsenosulphides, such as arsenopyrite (FeAsS), and cobalt arsenosulphide (CoAsS), that is, cobaltite, on silver salt solutions.

5. The silver precipitation capacity of a nickel or cobalt arsenide depends on the proportional amount of arsenic uncombined with sulphur, that is, the arsenic or simple arsenides.

The study of ore enrichment involves problems the solution of which requires a knowledge of the chemical properties of the homogeneous substances contained in many mineral mixtures, and there is much to be learned concerning the conduct of ore-forming minerals with metallic salt solutions which may come in contact with them. In future if as much attention is paid to the chemical conduct of minerals as has been directed hitherto to their total content, and to the determination of their physical properties, there is reason to believe that chemical mineralogy will become a more systematic and serviceable branch of mineralogical science than it is today.

A HYPOTHESIS FOR THE ORIGIN OF THE CARNOTITES OF COLORADO AND UTAH.

FRANK L. HESS.[1]

COMPOSITION.

Theoretically carnotite is an orthorhombic hydrous potassium uranium vanadate of a canary-yellow color. Another mineral, tyuyamunite, of similar color and the same crystal form and general appearance, contains calcium instead of potassium and it is probable that the so-called carnotite of the Utah and Colorado fields is nearly everywhere a mixture of the carnotite and tyuyamunite, molecules, forming a series which grades at either end into a mineral composed of only one kind of molecule, as do the plagioclases, wolframites, and other series minerals. According to conditions of occurrence, the carnotite may be powdery, friably massive, or sufficiently compact to cut like talc or wax, though the latter form is rare. In many analyses of carnotite, copper and soluble barium compounds are found and it is possible that they may replace the potassium or calcium. The mineral apparently belongs to a group in which the vanadium may be replaced by phosphorus, giving the torbernite series, or by arsenic, giving zeunerite or uranospinite. These relations are shown in the following table:

MINERALS OF THE URANITE GROUP.

Carnotite	K_2O	$2UO_3 \cdot V_2O_5 \cdot xH_2O$.
Tyuyamunite	CaO	
Not identified	$BaO?$	
	$CuO?$	
Torbernite	CuO	$2UO_3 \cdot P_2O_5 \cdot 8H_2O$.
Autunite	CaO	
Uranocircite	BaO	
Zeunerite	CuO	$2UO_3 \cdot As_2O_5 \cdot 8H_2O$.
Uranospinite	CaO	

[1] Published by permission of the Director of the United States Geological Survey.

OCCURRENCES.

As now known, the principal occurrences of carnotite are in that portion of the high plateau region which lies between the Rocky Mountains of Colorado and the San Rafael Swell of Utah, the Denver & Rio Grande Railroad, and the Arizona-New Mexico line. In this area the main deposits are in the vicinity of Paradox Valley, McIntyre Cañon, Mesa Creek, and Gateway, Colo.; the La Sal Mountains, Dry Valley, Yellow Cat Wash, the San Rafael Swell and the Henry Mountains, Utah. Sporadic deposits outside of this general region occur on Red Creek, Brown's Park, Uinta County, Utah; and in Routt, Rio Blanco and Eagle counties, Colo. As known at present, the richest deposits are those in the vicinity of Paradox Valley, with which is included Long Park.

Carnotite is not a common mineral, and is known at only four other places: Mauch Chunk, Pa.;[1] near Olary, South Australia;[2] at an indefinite locality in the interior of Brazil;[3] and the lime carnotite, tyuyamunite, is found at Tjua-Mujun in the Andijan district, Ferghana government, central Asiatic Russia.[4]

GEOLOGIC CONDITIONS.

In the main carnotite field of Colorado and Utah carnotite occurs in a nearly white cross-bedded sandstone, which ranges in thickness from 10 to 50 feet. In texture the sandstone is ordinarily medium-grained but in some places is very fine grained and in others is conglomeratic, the pebbles reaching an inch in longest diameter.

Fossilized wood and carbonized reeds or rushes are abundant and there are many bones in the bed. The wood is in the form of

[1] Wherry, Edgar T., "A New Occurrence of Carnotite," *Amer. Jour. Sci.*, Vol. 33, 1912, pp. 574–580.

[2] Crook, T., and Blake, G. S., "On Carnotite and an Associated Mineral Complex from South Australia," *Mineralogical Magazine*, London, Vol. 15 (March), 1910, pp. 271–284.

[3] Branner, J. C., private communication.

[4] Nenadkevich, K. A., "Tyuyamunite. A New Species of Mineral," *Imp. Acad. Sci. Bull.*, St. Petersburg, 6th Ser., November 1, 1912, pp. 945–946, and personal communication of Dr. Wladimir Vernadsky.

tree trunks some of which are as much as six feet in diameter at the base. The ends are rounded, the branches and roots are generally represented only by worn stubs, and the logs show the effect of having been washed from one beach to another before settling to a final resting place.[1] Mr. F. H. Knowlton, to whom I submitted specimens collected in 1911, states that the trees grew in a warm climate, as they do not show the annual rings due to periodic growing seasons. He is now studying other specimens collected in the fall of 1913.

Part of the wood is petrified and a smaller part is carbonized. Some is well preserved but some was much decayed before petrifaction. The wood was not petrified until long after it had been covered by later beds, for many logs have been crushed, so that they present oval cross sections. The sandstone is fairly friable and free from clay, and this means that it is not closely cemented and has considerable pore space. Most of the sandstone is cemented by silica, but in part the cement is calcite or gypsum. The characteristics of the sandstone are not particularly different from other beds both above and below, and no special reasons dependent upon structure, texture, or composition which would account for the precipitation or segregation of uranium and vanadium minerals in these rather than in other beds are apparent, except the greater content of fossil vegetation. The conditions under which the sandstone was laid down are therefore of importance in considering why the deposits are in these beds.

Cross-bedding in water-laid sandstones, which I consider these to be, seems necessarily to mean either shore conditions or very shallow water. The wide extent of the beds, which cover an area of thousands of square miles, precludes shore conditions over the

[1] These observations are in line with those made in western New Mexico by J. S. Newberry ("Report upon the Colorado River of the West Explored in 1857 and 1858 by Lieut. Joseph C. Ives," Part 3, 1861, pp. 78–80) and those of Lester F. Ward ("Status of the Mesozoic Floras of the United States," U. S. Geol. Survey 20th Ann. Rept., Pt. II., pp. 328–330) at the great "petrified forests" near Adamana, Arizona, which also occur in one of the cross-bedded sandstones (upper Triassic) spread over this great region. Both of these geologists found that the petrified wood in the cross-bedded sandstones was water-worn.

whole area. I assume that the known facts indicate that a broad, flat basin was occupied by a sea so shallow that steady winds blowing in any direction piled up the waters at the lee end and formed shifting sand bars at many places on which trees which had been washed from the surrounding shores lodged with rushes, reeds, and carcasses of animals.

AGE OF BEDS.

It is not to be supposed that geologists in general can keep in mind the age and succession of local formations, and I therefore give the following classification adopted by the United States Geological Survey of the rocks of southwestern Colorado and southeastern Utah.

CLASSIFICATION OF ROCKS.

System.	Series.	Formation.
Cretaceous	Upper Cretaceous	Mancos shale.
		Dakota sandstone.
Jurassic		McElmo formation.
Jurassic(?)		La Plata formation.
Triassic		Dolores formation.
Carboniferous	Permian(?)	Cutler formation.
	Pennsylvanian	Hermosa formation.

The carnotite-bearing beds have in general been regarded as of La Plata (Jurassic) age. There seems, however, reason to doubt the correctness of this general designation. Field work done during the fall of 1913 indicates that the Utah deposits, at least, lie in beds of McElmo age. So far as I am aware, the only geologic work bearing upon the carnotite deposits in the Paradox Valley region, results of which have been published, was that done by F. L. Ransome and A. C. Spencer in 1899, and by them the age of the rocks in which the carnotite occurs was given tentatively as McElmo[1] on La Sal Creek, and as La Plata on Roc Creek.[2] On the San Rafael Swell the carnotite-bearing sandstone has been determined by C. T. Lupton[3] as of McElmo age.

[1] Hillebrand, W. F., and Ransome, F. L., "On Carnotite and Associated Vanadiferous Minerals in Western Colorado," Bull. U. S. Geol. Survey, No. 262, pp. 14–15.

[2] *Op. cit.*, p. 16.

[3] Personal communication.

In the Henry Mountains, the La Sal Mountains, and in Dry Valley, 20 miles north of Monticello, the bed which carries the carnotite is apparently the same as that on the San Rafael Swell. At Placerville, beyond the eastern edge of the field, a little carnotite occurs as an accompaniment of vanadium-bearing sandstones which are positively known to belong to the lower part of the La Plata. It is notable that in this district no petrified wood or other vegetable matter is associated with the carnotite, which occurs mostly as an efflorescence along joint planes in roscoelite-bearing sandstone. This carnotite has evidently been formed by the breaking down of some mineral accompanying the roscoelite. In Routt and Rio Blanco counties the carnotite-bearing sandstone has been identified by Gale[1] as La Plata, and it seems probable that the occurrence in Eagle County may also belong to the same horizon, for the Hayden Survey Atlas shows outcrops of "Jura-Trias" ("Variegated beds") in this general locality. On Red Creek, in northeastern Utah, the occurrence is wholly different. Here tyuyamunite, the calcium carnotite, occurs with more or less copper carbonate along joint planes in a white quartzite which may be of pre-Cambrian age.

CLOSELY RELATED DEPOSITS.

At a number of places deposits of other uranium minerals occur adjacent to the carnotite-bearing area. Near Fruita, Wayne County, Utah, a uranium sulphate is found with copper carbonates in a thin lens of sandstone in rocks which are considered by Lupton[2] to be of Vermillion Cliff age, and to correspond to the Dolores formation (Triassic) of Colorado. Near Pahreah, close to the southern edge of the State, autunite and uranospinite are reported[3] to occur along joint planes in a white sandstone of unknown age. In Temple Mountain, on the San Rafael Swell, uranium and vanadium minerals of uncertain composition occur

[1] Gale, H. S., "Carnotite in Rio Blanco County, Colo.," U. S. Geol. Survey Bull. 315, pp. 110–117, 1907; "Carnotite and Associated Minerals in Western Routt County, Colo.," U. S. Geol. Survey Bull. 340, 1908, pp. 258–259.

[2] Personal communication.

[3] Specimens have been received through the courtesy of Dr. W. H. Schock, of Richfield, Utah.

in sandstones which are probably of Dolores age. The minerals from this locality are now being chemically investigated in the laboratory of the United States Geological Survey. Several other sporadic occurrences are also known.

OCCURRENCE OF THE CARNOTITE.

In general the carnotite of the area under consideration occurs in flat lenticular deposits, only a few of which are known to reach more than 100 feet in length and width. They are from a few inches to four or five feet in thickness, conform to the cross bedding of the sandstone and are in some places forked from following two cross-bedding planes which happen to meet in a line. The deposits of the main area are invariably connected with fossilized plant remains.

The carnotite most commonly fills spaces in the sandstone, either filling breaks in the cementing material or coating joints in the rock and the sides of cracks in fossil wood. Much of it so found appears to the unaided eye to be a powdery amorphous mass though under the microscope it shows a crystalline structure. Along some joints, especially if the carnotite is in very small quantity, the crystalline structure is evident, though the crystals are small, probably less than one fourth of a millimeter across, and are generally in radial groups. The carnotite also fills cavities in sandstone, petrified wood and carbonized rushes, and sometimes replaces wood with a comparatively solid mass. In Bull Canyon, south of Paradox Valley, a tree trunk between 50 and 100 feet long was replaced by a mass very rich in carnotite[1] and similar occurrences are reported from Long Park, north of Paradox Valley. In these replacements and in their occurrence with fossil vegetation the deposits greatly resemble the copper deposits in the sedimentary beds of this and adjacent regions. Schrader[2] describes, as occurring in the Triassic "Red Beds"

[1] Cummings, W. L., oral communication.

[2] Schrader, F. C., "The Ore Deposits of New Mexico," U. S. Geol. Survey Prof. Paper 68, p. 147, 1910. The replacement of tree trunks by copper minerals in this general region (near Abiquiu) was noticed as early as 1859 by J. S. Newberry, though his report was not published until 1876—"Rept. Exploring Expedition from Santa Fe, N. Mex., to the junction of the Grand and Green rivers, etc." Washington, 1876, pp. 68–69.

of northwestern New Mexico, tree trunks as large as 60 feet long and 2½ feet in basal diameter, which were almost completely replaced by chalcocite. Vegetable remains more or less replaced by copper sulphides, in many places altered to carbonates, are common to nearly all known copper deposits in the sedimentary rocks of the high plateau region. Carnotite is not known to occur without an accompaniment of other vanadium minerals, hydrous iron oxides, and in many places, copper and chromium minerals. In the ores mined vanadium is always in excess of the uranium. Commonly carnotite occupies the middle of a deposit and around it the sandstone is impregnated with undetermined black vanadium minerals, the calcium vanadates, hewettite and metahewettite and in places volborthite and calciovolborthite. Still farther out the sandstone is stained with iron oxide, and in some places with a green chromium mineral. Selenium has been found with the vanadium minerals at many places. It is possibly in part elemental as suggested by Dr. Hillebrand in our conversation. In a very few deposits iron sulphide is found.

Where carnotite occurs in fossil wood the degree of decay seems to have largely governed the quantity of replacement. On the Amarillo claim, in the La Sal Mountains, a length of more than 20 feet of a forked petrified tree was mined for ore, and in the tree the uranium was richest around the outer edge—the part which was evidently most decayed. Wood that shows its structure well carries little carnotite, and, except in small quantities which occupy cracks, carnotite does not accompany the carbonized wood which occurs here and there in the sandstones. In this its occurrence is also like that of copper sulphides in the sediments of the high plateaus. My examination of typical specimens in which carbonized wood is supposed to have been replaced by copper sulphides has developed the fact that the cells of the wood, at least in part, have been well preserved. In carbonized wood, however, the cells are always collapsed and have largely or wholly lost their identity. In these supposed replacements, therefore, not alone was the coal not replaced, but

only that part of the wood which was not replaced by copper or other minerals has been carbonized. The same reasoning will undoubtedly apply to uranium and vanadium minerals.

Exposed ends of fossilized sticks a quarter of an inch in diameter have been found which have around them an aureole of carnotite and hydrous iron oxide 1½ inches in diameter. The sticks are now represented mostly by limonite. These occurrences illustrate vividly the migration of carnotite away from vegetable remains, a dissipation of the oxidized minerals from the original deposit which I believe to be the ordinary movement under present conditions. I observed a precisely similar phenomenon in a copper deposit near Ouray, Utah.

The relations of the carnotite and the fossil vegetation in the sediments of the area may be summed up thus:

1. Carnotite deposits always contain fossil vegetation.

2. Spaces in the rocks, which were formerly occupied by vegetation, including large trees, are now occupied by carnotite and associated minerals.

3. The fossil wood was floated to its resting place and was not petrified until it had been buried rather deeply.

4. Neither carbonized nor silicified wood has been replaced by metallic minerals.

5. Carnotite is an oxidized mineral which may have migrated some distance from its original position. Aureoles show that under present conditions carnotite and other metallic minerals are moving away from rather than toward fossil wood.

ORIGIN OF THE ORES.

A number of suggestions have been advanced for the origin of the carnotite.

Ransome[1] states:

> "That the bodies of carnotite and roscoelite were formed subsequently to the deposition of the sandstones is evident from the facts presented in the preceding pages. It is equally plain that the minerals could not have resulted from the alteration, in place, of other compounds of vanadium and uranium originally contained in the sands. The shape

[1] *Op. cit.*, p. 17.

and position of the deposits indicate clearly that the ores have been brought to their present position by transportation. Moreover, the recency of the deposits and the fact that they are sometimes directly connected with faults and dislocations in the sandstones show that the vanadium and uranium compounds could not have been the original cementing material of the quartz grains, but in all probability they have locally replaced the calcite that acts as matrix to the ordinary light-colored sandstone in which the ore bodies occur.

"The carnotite appears to be of superficial occurrence, and its connection with the present surface of the ground is not yet fully understood. This would indicate that the carnotite results from a local concentration of material already existent in the sandstone, and the deposition of this material in the form of carnotite under conditions determined by proximity to the surface, and probably partly dependent upon a semiarid climate."

The principal "facts in the preceding pages" to which he refers appear to be these:[1]

"The carnotite of La Sal Creek occurs as irregular bunchy 'pockets' in the sandstone, or along the contact of the sandstone with the underlying shale. These have all the appearance of being impregnation deposits, the solutions carrying the uranium compounds having deposited the ore wherever they found ready passage through the rock—usually along bedding planes. No roscoelite was seen with the carnotite.

"The most remarkable and interesting fact in regard to the La Sal Creek deposits is their very superficial character. The ore bodies are usually flat-lying streaks, a few inches thick, which grade above and below into the common light-buff sandstone, and which die out and disappear when followed into the hillside. In tunnels that run but a few feet underground the yellow impregnation of carnotite can be seen gradually to die out and to be succeeded by light-colored sandstone, showing no trace of the mineral. It is doubtful whether any appreciable quantity of carnotite occurs as much as 20 feet from the surface, on any of the locations, although this distance is given from memory and not from measurements on the ground. As before stated, the impregnation has usually taken place along bedding planes; it has also proceeded along surfaces of minor and superficial movement in the rocks. In one case it was observed that a portion of the overlying sandstone had moved upon the underlying shales, the disturbance being apparently a superficial one, of a kind commonly enough observed where massive beds rest on yielding shales on a steep hillside. In other words, the movement appeared to be directly related to the present topography. The carnotite

[1] *Op. cit.*, pp. 15–16.

was here deposited subsequent to the movement and had filled the small openings and dislocations in the shale caused by this very recent disturbance. . . .

"There can be little doubt that the deposits of carnotite on La Sal Creek are not only very superficial in character but very recent in age. This deposit is similar in character to others examined, except that in this case a well-defined fault has provided a zone of crushed and porous rock in the hanging wall, along which impregnation could take place."

Since Ransome and Spencer visited the area certain of the deposits have been followed under much deeper cover than indicated in the description quoted. Moore and Kithil[1] mention that 200 feet of drifting has been done on one claim, and come to the view that

"On practically all (the carnotite bearing properties) there seems to be a direct relation between the overburden and the quantity and grade of the ore, the latter improving where the overburden is thicker."[2]

Fleck and Haldane[3] suggested that veins of a vanadiferous pitchblende had been worn down, the débris had been washed into the La Plata sea and the uranium and vanadium from the decaying particles had collected as carnotite. However, as they admit, no highly vanadiferous pitchblende has ever been found, but they believe it may yet be discovered. Lindgren[4] without designating the minerals, similiarly believes in an origin from minerals washed in with the sand and points to the very wide distribution of vanadium as shown by Hillebrand,[5] to confirm the probability of such a source, but no such wide distribution of uranium has been shown if we except the infinitesimal quantities indicated by the radioactivity of air, water and rocks.

[1] Moore, Richard B., and Kithil, Karl L., "A Preliminary Report on Uranium, Radium and Vanadium," U. S. Bureau of Mines Bull. 70, p. 23.

[2] *Op. cit.*, p. 28.

[3] Fleck, Herman, and Haldane, W. G., "A Study of the Uranium and Vanadium Belts of Southern Colorado," Rep. State Bureau of Mines (Colorado) for 1905–1906, pp. 56–57, 1908.

[4] Lindgren Waldemar, "Copper, Silver, Lead, Vanadium, and Uranium Ores in Sandstone and Shales," ECON. GEOL., Vol. 6, 1911, p. 79.

[5] Hildebrand, W. F., "Distribution and Quantitative Occurrence of Vanadium and Molybdenum in Rocks of the United States," U. S. Geol. Survey Bull. 167, pp. 43–78, 1900.

Moore and Kithil[1] also hold a similar belief. They have attacked the problem by determining the radioactivity of the rocks and find that in the vicinity of Paradox Valley the sandstones above the deposits are much more radioactive than those below them. They think this indicates that the uranium was derived from particles in the sandstone itself. If the material were collected from the sandstone itself it is difficult to see why only the sandstone above the carnotite deposits should be especially radioactive. If the minerals had been almost equally distributed through the beds, it would seem that those from both the upper and the lower part should show nearly the same radioactivity.

The suggestion has naturally arisen that the deposits are in some way connected with igneous rocks, such as those of the La Sal and Henry Mountains and the intrusive masses that are believed to underlie the San Rafael Swell, but no veins carrying either uranium or vanadium have been found at any of these places; nor have veins been found in McElmo rocks at any place in the area.

Derivation from asphaltic materials has been suggested but asphaltic material has been found with uranium minerals only at Temple Rock and in very small quantity at Fruita. It is doubtful whether carnotite exists at either place and the rocks are probably of early La Plata or late Dolores age at Temple Rock, and are of Dolores age at Fruita.

One of the most notable features of the carnotite deposits described is that most of them occur in a single bed of sandstone, probably of McElmo age. As stated, this bed has no characteristics as to cementation or lack of it, or as to the kind of cement or of contained minerals that might act as precipitants, which would distinguish it from beds above or below. It is in small part bonded by calcite, as are others. It is not peculiar in being cross-bedded, as there are in this region many other cross-bedded sandstones, both older and younger. It probably carries more organic matter than any of the beds below it, though other beds

[1] Moore, Richard B., and Kithil, Karl L., "A Preliminary Report on Uranium, Radium, and Vanadium," U. S. Bureau of Mines Bull. 70, pp. 30–31, 1913.

carry petrified logs and many remains of reeds, but in these other beds little or no uranium has been found.

I have mentioned that the degree of decay of the wood before it was petrified apparently governed, at least in part, the quantity of carnotite present, and that the carnotite occurs with carbonized reeds or rushes—quickly decomposed organisms,—and these facts would indicate that the original minerals of which carnotite is an oxidation product had been precipitated upon coming in contact with organic matter and therefore must have been deposited before the silicification of the organic bodies, so that the original minerals were introduced into the bed either at the time of its deposition or before its solidification.

At this point I wish to notice some known uranium and vanadium-bearing veins in the drainage area of the Jurassic-Triassic sea.

On Red Creek, Utah, as already noted, tyuyamunite occurs with copper carbonates along joint planes in pre-Cambrian (?) quartzite. The minerals have been derived from a vein following crushed zones in the quartzite and evidently accompanying basic dikes, of unknown age, which carry copper sulphides and are folded in the quartzite. In Boren Gulch, La Plata County, Colorado, a vein carries vanadium minerals and several assayers have reported uranium though none has been found in specimens sent to the Survey.

At Placerville, Colorado, is a vein which carries a little uranium and vanadium, a hydrocarbon, copper, gold, silver, barium, and other minerals, and a chromium mineral in the enclosing rock appears to owe its origin to the vein. I could not follow this nor similar veins above the rocks of La Plata age.

In the La Plata itself are vanadium deposits accompanied by uranium and chromium, and these deposits I consider to be veins with impregnation of the adjacent sandstone.

From the consideration of these data I am led to propose as a working hypothesis for the origin of the main carnotite deposits that in the breaking down of the veins just described similar to those, the sulphuric acid formed through the oxidation of pyrite and other sulphides combined with uranium, vana-

dium, copper, silver, iron, and possibly chromium minerals of the veins to form soluble sulphates which were carried into the shallow sea which existed during La Plata and McElmo time and were there diffused and brought into contact with decaying organic matter by which the sulphates were reduced, the uranium possibly to an oxide or to a combined sulphide with vanadium or copper or both and the vanadium, copper, silver and iron to sulphides. Upon the lifting, draining and aerating of the rocks the minerals were oxidized and part of the vanadium formed vanadic acid, which combined with uranium and potassium or calcium to form carnotite or tyuyamunite.

The question may be asked, why should the uranium and vanadium have been weathered from these veins almost wholly during La Plata and McElmo time, and only a little at earlier times? It may be replied that in many veins which extend to great depths, the metallic minerals are most abundant in certain zones and this seems to be particularly true of minerals of the rarer metals. In the weathering of such veins there will be some period of time during which the great bulk of the minerals will be removed, and I assume that such removal occurred in McElmo time in this area. The erosion of the original uranium and vanadium deposits evidently began in La Plata, Dolores, or possibly earlier time, and it is possible that one or two of the specific veins which I have mentioned are existing remnants of such deposits.

That uranium may have been deposited with copper as a sulphide seems to be shown by a copper deposit on the south side of White Canyon, fifteen miles northeast of Hite, Utah. Here sulphides, of which that of copper alone has been identified, are breaking down and various sulphates are deposited as the solutions seep out at the surface, and with them uranium is now being deposited in small quantities, evidently also as a sulphate.

Let me emphasize the point that this is offered only as a working hypothesis, a tentative tool to be cast aside like any other if unsuited to the job. It, however, seems to me to offer an explanation of the phenomena of the deposits so far as observed. Unfortunately I have not yet been able to study at first hand the

best and richest deposits—those in the general region of Paradox Valley, but I have corresponded and conversed with many who are familiar with them, and the deposits seem to conform to the general type seen in Utah. Future studies may, of course, cause the rejection of a part or the whole of the hypothesis.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

TOURMALINE-BEARING QUARTZ VEINS.

Sir: In Vol. IX., No. 2, of ECONOMIC GEOLOGY there appeared a very interesting paper by Mr. A. H. Means entitled "Tourmaline-Bearing Quartz Veins of the Michipicoten District, Ontario." On the first page of his paper he writes as follows:

"The district is situated in a large area of Lower Huronian schists into which post-Huronian granites and other acidic and basic igneous rocks have been intruded. The age of these intrusives is considered as Keweenawan.

"A mile or two to the north of Wawa Lake is a small area of the iron-bearing Helen formation, also Lower Huronian, in which the Helen iron mine is situated."

Believing that Mr. Means has in some way overlooked the nomenclature adopted by the pre-Cambrian committee of 1905, and which has been used ever since, the writer wishes to call attention to the fact that the Helen formation has been considered as Keewatin in age. In confirmation of this, reference may be made to the following reports of later date than those mentioned by Mr. Means: (1) Coleman, Ontario Bur. Mines, Vol. XV., 1906, p. 174. (2) Van Hise and Leith, U. S. G. S. Mon. 52, 1911. (3) "The Significance of recent developments in the Pre-Cambrian Stratigraphy of the Lake Superior-Lake Huron Region," M. E. Wilson, *Jour. of Geology,* Vol. 21, 1913.

N. B. DAVIS.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

Compiled by

Sidney Paige and F. J. Katz.

METALLIC.

GOLD AND SILVER.

Die Proplitisierung, Kaolinisierung und Verkieselung und ihre Beziehung zu den Lagerstattung der propylitischen jungen Gold-Silber Gruppe. By M. Lazarevicz. Zeit. f. prakt. Geologie, Aug., 1913, pp. 345–361.

Presents a brief review of the theories of these alterations in andesitic-dacitic rocks and the author's conclusions from studies on the rocks and ore deposits of Hungary, Servia and other regions. It is held that propylitization, kaolinization, and silicification, in the formation of rocks in the regions considered, are successive and related results of igneous after processes—*i. e.*, the work of ascending solutions of magmatic origin—that they are not dependent upon formation of ore deposits, but rather that they partly precede ore formation which is a younger stage in the same series of alterations. Two types of propylitization, zeolitic and pyritic, are recognized. Kaolinization is held to be distinct from the formation of aluminous minerals (including alunite) in the walls of ore bodies by secondary descending sulphuric acid solutions. Silicification only is so closely associated with ore formation as to furnish a guide to ore location.

Die neueren Fortschritte in der Erforschung der Goldlagerstatten Sibiriens. By J. Ahlburg. Zeit. f. prakt. Geologie, Mar. and Apr., 1913, pp. 105–188.

Includes a review of the important literature, an outline of the geology of Russian Asia, and geologic descriptions of gold mining regions of Siberia with comparative statistics on the several productive regions. The regions discussed are the Kirgese Steppes, the South Altai, the Northwest and Central Altai, the East Altai or Kusnetzky-Alatau, the Sajan Mountain System, the Yenissei, the Lena, the Lake

Baikal Highland, the East trans-Baikal, the Amur, and the Coast provinces.

LEAD AND ZINC.

The Zinc-Carbonate Ores of Leadville. By PHILLIP ARGALL. Mining Magazine, April, 1914, p. 282. 6 figs.

Briefly reviews the geology of the district and describes in detail the occurrence of the carbonate ores which are replacements of limestone. Total output from these ores amounted to 187,000,000 lbs. of zinc, at close of 1913.

Some Cerusite Deposits in Custer County, Colo. By J. FRED HUNTER. Bulletin 580–C, U. S. Geol. Survey. 2 figs., 37 pages.

Veins along zones of faulting. Galena from which the cerusite has been derived should be expected with increasing depth.

COPPER

The Grand Gulch Mining Region, Mohave County, Arizona. By J. M. HILL. Bulletin, U. S. Geol. Survey, No. 580–D. 5 figs., 56 pages, with bibliography of Copper ores of the "Red Beds."

The Copper Handbook. Founded by Horace J. STEVENS. Published by Walter Harvey Weed, Houghton, Mich., 1914. Vol. XI., 1912–13, supplementing Volumes I.–X.

A manual of the Copper mining industry of the World.

Über einen neuen Typus einer Lagerstätte von gediegen Kupfer auf Nowaja Semlja. By F. W. VOIT. Zeit. f. prakt. Geologie, Jan., 1913, pp. 42–49.

Calcareous and slaty Devonian sediments are intruded by basic (diabase) rocks. The ore bodies which are of unproved size or importance are (1) primary and unimportant copper sulphides impregnating diabase and small veins of calcite and chalcopyrite with occasionally chalcocite and bornite in diabase; (2) secondary native copper in what the author calls diabase-propylite. Very brief descriptions of the diabase and "diabase-propylite" and ore bodies are given and the author concludes that the "propylite" is either distinct magma injected into normal diabase before the latter was completely solidified or that the "propylite" bodies are the upper surface of diabase flaws.

Die kupfererzführenden Buntsandsteinschichten im Fürstentum Waldeck. By K. BODEN. Zeit. f. prakt. Geologie, Feb., 1913, pp. 85–89.

Presents description of copper bearing sandstones having an average copper content of 1 per cent.

Presents a description of copper bearing lower Triassic (Bunter) sandstones and clays in Waldeck, central Germany. The copper content ranges up to 4 per cent., averages 1 per cent., and is in the form of malachite, azurite, and chalcocite; the ores are always concentrated around organic substances. Ore formation is held to be epigenetic, viz., precipitation by organic materials of copper from solutions which entered crevices in the sandstone after their deposition. The ores were worked in the sixteenth and eighteenth centuries, and again unsuccessfully attempted in 1853–63.

IRON.

Texas Iron Ore Deposits. By ROBT. LINTON. Eng. and Min. Journal, Vol. 96, No. 25, Dec. 30, 1913.

Iron ore in commercial deposits occurs in about 20 counties in Texas, but the number of mines where distributed is not large. The best are found in Cass County and those immediately adjoining. The deposits are discontinuous, overlapping parallel beds or sheets of brown ore and sphathic ore cropping generally on or near hill tops. They occur in Eocene sediments of sands and clays. Methods of working, grade of ore and physical characteristics are noted in detail. A map and cross section is given.

Austin Brook Iron-bearing District, New Brunswick. By EINAR LINDERMANN. Mines Branch, Department of Mines, Canada. 1913. 15 pp., III. plates, 5 figs., 3 maps.

Magnetic ore bodies of siliceous magnetite mixed with hematite are associated with quartz porphyry and schist bands. Average iron content 43–47 per cent.; phosphorus .8; sulphur .03 to .1. Extent of ore bodies are estimated and mining operations described.

Les Resources de la France, En Minerai de fer. By P. NICON. H. Dunod et Pinot, Paris, 1911. 105 pp. Maps and figures.

A supplement to the report made for the "Iron Resources of the World" with additions of historic notes. Statistics and information not available in 1909.

Allgemeine Geologie Schwedens und Geologie der Eisenerzlagerstatten von Kiruna und Gellivare. Berichte über Exkursionen des 11. Internationalen Geologenkongresses zu Stockholm. By H. ARLT. Glückauf; Berg und Huttenmännische Zeitschrift, Vol. 47, Nos. 19 and 20, 1911. (— 24 pp.)

Brief review of the geology of Sweden and of the iron ore deposits of Lapland.

TITANIUM AND APATITE.

Geology of the Titanium and Apatite Deposits of Virginia. By THOMAS LEONARD WATSON and STEPHEN TABER. Bulletin No. 111–A, Virginia Geological Survey. 297 pp., XXXVII. plates and 22 figures.

This report contains a discussion of the geology of titanium (rutile and ilmenite) and apatite deposits of Virginia, including (*a*) the Amherst-Nelson counties area, (*b*) the Roanoke County area, (*c*) the Goochland-Hanover counties area, and (*d*) the occurrence of rutile in Charlotte and Buckingham counties, which is of scientific interest but not of commercial importance.

The first two chapters are of general interest, and the remainder of the report treats of other districts in Virginia and closes with a discussion of economic aspects, the uses of titanium and its compounds, and a bibliography of titanium.

TIN.

The Pyrrhotite Tin Vein of the Mitate Mine, Higen Province, Japan. By TAKEO KATO. The Journal of the Geol. Society of Tokyo, Vol. XXI., No. 247, Apr., 1914. 2 plates.

Describes in detail very unusual bedded tin-bearing pyrrhotite vein between quartzite handing and limestone footwall of contact metamorphic origin and showing remarkable alteration of hanging wall and footwall.

PLATINUM, ALUMINUM, AND RARE MINERALS.

Carnotite, I and II. By THOS. F. V. CURRAN. (I) Engineering and Mining Journal, Dec. 20, 1913. (II) Engineering and Mining Journal, Dec. 27, 1912.

A description of the mineral, which containing vanadium and uranium, is radio-active and the principal source of radium. In the United States it occurs principally in Colorado and Utah. Describes dressing of ore and manufacture of compounds. Special units are used for measuring radio-activity.

Sur les Sables Noirs de Madagascar Et leur prétendue richesse en platine. Par L. DUPARC. Archives des Sciences physiques et Naturelles; cent dex-huitieme anule, quatrieme periode.

Shows that the rocks of Madagascar are acidic and unlikely to contain platinum and by examination of a number of samples, substantiates this view.

Bauxite in Tennessee. By A. H. PURDUE. The Resources of Tennessee, April, 1914. Published by Geol. Survey. 2 figs.

Describes nature and uses of bauxite and its occurrence in Tennessee.

GENERAL.

Lode Mining in the Ketchikan Region, Alaska. By PHILIP S. SMITH. U. S. Geological Survey, Bulletin 592–B, pp. 75–94.

Describes briefly the various districts of the Ketchikan region.

The Geology of the Rolla Quadrangle. By WALLACE LEE. Missouri Bureau of Geology and Mines, Vol. XII., second series.

Contains account of resources in barytes, fire-clay, lime, building stone, iron, sand, gravel, road materials, lead and zinc, coal, oil, and gas, Tripoli onyx, gold and silver.

Wheaton District, Yukon Territory. By D. D. CAIRNES. Memoir No. 31, Geological Survey of Canada, Ottawa, 1912. 146 pages. XIV. plates, 10 drawings, 4 maps.

District economically important for its (1) gold-silver quartz veins (with tellurides), (2) antimony-silver veins (both metals of importance), (3) silver-lead veins (metasomatic replacements), (4) contact metamorphic copper deposits (peculiar in being developed in an igneous hornblende gneiss).

Some Ore Deposits in Northwestern Custer County, Idaho. By J. B. UMPLEBY. Bulletin, U. S. Geological Survey, No. 539, 1913. 104 pages, 10 plates, 4 text figs.

This report sets forth the result of a short reconnaissance in the Loon Creek, Yankee Fork, and Bay Horse mining districts, situated in the northwestern part of Custer County, Idaho. The area includes several promising ore deposits and a few mines where a considerable tonnage is blocked out, awaiting more advantageous transportation facilities.

A Geologic Reconnaissance of the Circle Quadrangle, Alaska. By L. M. PRINDLE. Bulletin, U. S. Geological Survey, No. 538.

Geology and Geography of a Portion of Lincoln Co., Wyoming. By ALFRED REGINAL SCHULTZ. Bulletin No. 543, U. S. Geol. Survey. 137 pages XI. plates, 8 figs.

Coal, oil, gold.

Useful Minerals of the United States. By SAMUEL SANFORD and R. W. STONE. Bulletin 585, U. S. Geol. Survey.

An alphabetical list of minerals, giving localities at which the minerals occur in sufficient quantity to be of present or possible future value, with a glossary showing definitely what is meant by the terms used in the text of the bulletin.

Die Mineralschätze Tunesiens. By H. ARLT. Glückauf Berg und Huttenmannische Zeitschrift Vol. 49, Nos. 29 and 30, pp. 1129–1134 and 1169–1179.

A brief review of the iron, zinc-lead, and phosphate deposits and mining in Tunisia.

Contributions to Economic Geology, 1911 (short papers). MARIUS CAMPBELL, in charge. Bulletin 531, U. S. Geol. Survey, 1913.

Geology and Mineral Deposits of the Tulamean District, B. C. By CHAS. CAMSELL. Memoir No. 26, 181 pp., 23 plates, 2 figs., 4 maps.

The Tulamean district first attracted the atention of the mining public to its placers—and to the present only the placers have been profitably worked. Since 1885, 800,000 has been produced in gold and platinum. The lode deposits of the district are in the prospect stage. The discovery of diamonds in the original peridotite matrix has stimulated exploration. The geology of the region is described in detail.

NON-METALLIC.

COAL AND OIL.

Oil and Gas Fields in Wayne and McCreary Counties, Kentucky. By M. J. MUNN. Bulletin, U. S. Geol. Survey, No. 579. VI. plates, 6 figs. 103 pages.

Oil and Gas Prospects of the Northwest Provinces of Canada. By WYATT MALCOLM. Memoir No. 29–E, Canadian Geol. Survey, IX. plates, 2 figs. 1 map. 93 pages.

While the presence of oil in commercial quantity remains to be proved, boring operations have demonstrated beyond a doubt, the existence of large reservoirs of natural gas.

Geological Notes to Accompany Map of Sheep River Gas and Oil Field, Alberta. By D. B. DOWLING. Geological Survey of Canada, Ottawa. 1914. Map and cross section.

Boring on Sheep River has demonstrated presence of small quantities of oil in the Belly River rock of the Cretaceous. The locality is a good one structurally, at which to explore the underlying Cardium and Dakota sandstone.

Oil Shale of Northwestern Colorado and Northeastern Utah. By E. G. WOODRUFF and DAVID T. DAY. U. S. Geol. Survey, Bulletin 581–A, 1914. 1 plate, 21 pages.

"Beds contain a large reserve supply of oil which sooner or later will be used to supplement the product of the well-known oil field."

Coal and Lignite Fields in Montana. Papers by: C. M. BAUER, G. S. ROGERS, and C. F. BOWEN. U. S. Geol. Survey, Bulletin 541–H. 1914. 6 plates, 3 figs., 83 pages.

The Cannonball River Lignite Field, North Dakota. By E. Russell Lloyd. U. S. Geol. Survey, Bulletin 541–G. 2 plates, 1 fig., 51 pages.

Coal Fields in New Mexico and Utah. Papers by: Carroll H. Wegemann, and Frank R. Clark. U. S. Geol. Survey, Bulletin 541–J. 74 pages, 4 plates, 2 figs.

Coal Mining Practice in District VII. By S. O. Andros. Bulletin No. 4 of the Illinois Coal Mining Investigations. Published by University of Illinois. 53 pp. Illustrated.

Coal Mining Practice in District V. By S. O. Andros. Bulletin No. 6 of the Illinois Coal Mining Investigations. Published by University of Illinois.

Coal Mining Practice in District I. (Longwall). By S. O. Andros. Bulletin No. 5 of the Illinois Coal Mining Investigations. Published by University of Illinois. 42 pages. Illustrated.

The Coal Fields and the Coal Industry of Eastern Canada. By Francis William Gray. Trans. Inst. of Mining Engineers, Vol. XLVI., Pt. 1, London, 1913.

The Coal Resources and General Geology of the Pound Quadrangle, in Virginia. By Chas. Butts. Bulletin No. IX., Virginia Geological Survey, 1914. (Prepared in coöperation with the U. S. Geol. Survey.) 1 fig., 3 plates.

Coal-bearing rocks have a thickness of 4,800 feet. Available coal computed at 4,295,272,312 short tons; rocks generally flat, and coal beds can be exploited by drift mines. Destined to become one of the principal coal-producing centers of the central Appalachian coal field.

The Geology of the Northwestern Part of the Waukie Coal Field and the Coal Resources of Rhodesia. By B. Lightfoot and H. B. Maufe. Geol. Survey of Rhodesia, Bulletin No. 4, XV. plates.

WATER.

Geology and Ground Waters of Florida. By George Charlton Matson, and Samuel Sanford. U. S. Geol. Survey, Water Supply Paper 319. 1913.

The Ohio River Basin. By A. H. Horton, M. R. Hall, and H. J. Jackson. Water Supply Paper No. 303, U. S. Geol. Survey, 1913.

South Atlantic Coast and Eastern Gulf of Mexico Drainage Basin. By M. R. Hall and C. H. Pierce. U. S. Geol. Survey, Water Supply Paper No. 302. Part II.

Groundwater in Boxelder and Tooele Counties, Utah. By Everett Carpenter. U. S. Geol. Survey, Water Supply Paper 333, 1913.

Artesian Water Resources of South Australia. An appendix to Annual Report of the Government Geologist, Adelaide, 1913.

Geology of Saratoga Springs and Vicinity. By H. P. CUSHING and R. RUEDEMANN. New York State Museum Bulletin 169, 170 pp. Plates and maps.

Describes in detail the geology of the region. Emphasizes the relation between structure and the probable source of the carbonated waters. Suggests the metamorphism of impure limestone as a source of CO_2.

Underground Waters of Luna County, New Mexico. By N. H. DARTON. U. S. Geol. Survey, Water Supply Paper No. 345–C, 1914. 40 pages, 1 map.

Ground Water for Irrigation in the Valley of North Fork of Canadian River near Oklahoma City, Oklahoma. By A. T. SCHWENNESEN. Water Supply Paper, U. S. Geol. Survey, No. 245–D. 1 map, 51 pages. 1914.

Die Quellen des Kantons Thurgau. By J. ENGELI. Mitth. d. Thurgauischen Naturforschenden Gesellschaft. Frauenfeld, 1913. Heft XX., pp. 3–120.

A description of all the springs of the canton Thurgau including data on the amount of flow, the character of the water, and its utilization.

Grundwasser studien IV Uber die Wirkungen bedeutender Grundwasser-Absenkungen. By K. KEILHACK. Zeit. f. prakt. Geol., Aug., 1913, pp. 362–378.

A study of notable and long continued sinking of the ground-water table resulting from pumping to drain an open pit mine in Niederlausitz, Germany.

Beobachtung über Wassernutzung in China. By ERNEST BOERSCHMANN. Zeitschrift d. Gesellschaft für Erdkunde zu Berlin, 1913, No. 7, pp. 516–538.

Grundwasserstudien—V. Der Einfluss des trockenen Sommers 1911 auf die Grundwasserbewegung in den Jahren 1911 und 1912. By K. KEILHACK. Zeit. f. prakt. Geologie, Jan., 1913, pp. 29–41.

MISCELLANEOUS.

Late Developments of Magnesite Deposits in California and Nevada. By HOYT S. GALE. Bulletin, U. S. Geol. Survey, No. 540–S, 1913.

Describes the general character and distribution and use of magnesite. The deposits of California and Nevada are described in detail.

Der Genesis der Krystalline Magnesite und Siderite. By K. A. REDLICH and O. GROSSPIETCH. Zeitschrift f. prakt. Geologie, Feb., 1913, pp. 90–101.

Discusses the paragenesis of the Steiermark magnesite and siderite deposits and ascribes their genesis to metasomatic alteration of limestones by magnesian and iron-bearing waters.

Der Carbonzug der Veitsch und seine Magnesite. By KARL A. REDLICH. Zeitschrift für praktische Geologie. Sept., 1913, pp. 406–419.

Brief history of mining of the deposits and statement of the geology and mineralogy of the magnesite deposits of Veitsch, Steiermark.

A New Gypsum Deposit in Iowa. By GEORGE F. KAY. Bulletin 580–E, U. S. Geological Survey, 1914.

Describes a deposit of gypsum in the Mississippian rocks of southern Iowa, 500 feet beneath the surface. Deposit may be extensive. Anhydrite may decrease the value of the deposit.

The Gypsum and Salt of Oklahoma. By L. C. SNIDER. Bulletin No. 11, Oklahoma Geological Survey, July, 1913.

De Santa Barbara Fosfaatmijn op het Eiland Curacao. De Fosfaatmarkt, een Technisch-Commercieels Studie ober de Behoefte aan, de Productie en Waarde von Fosfaat. By J. A. GRUTTERINK. Verhandelingen von het Geologisch-Mijnbouwkundig Genootschap voor Nederland en Kolonien, Mynbouwkundige Serie., Oct., 1913, Deel L., pp. 91–189.

A Report on the Phosphate Fields of South Carolina. By WM. H. WAGGAMAN. Bulletin, U. S. Dept. of Agriculture, No. 18, Oct., 1913.

The Brown and Blue Phosphate Rock Deposits of South-Central Tennessee. By J. S. HOOK. The Resources of Tennessee, Apr., 1914. Published by State Geological Survey.

A paper of general interest, on the forms of the deposit, geographic distribution, extent of fields, method of mining and preparation, etc. Deposits are in part residual, due to weathering of phosphatic limestones; in part unenriched limestones.

Zur Frage der Genesis der Steinsalz- und Kalisalzlagerstätten im Tertiar vom Ober-Elsass und von Baden. By E. HARBORT. Zeit. f. prakt. Geologie, Mar. and Apr., 1913, pp. 189–198.

Presents a review and critical discussion of the theories of genesis of the potash salt deposits of Alsatia and directs attention to an apparent relation between the occurrence of petroleum and salt deposits.

Die Lagerungsverhältnisse des oberen Allertales zwischen Morsleben und Walbeck. By W. KIRSCHMANN. Zeit. f. prakt. Geologie, Jan., 1913, pp. 1–27.

Stratigraphy and structure of the upper Allertal formations with a discussion of the hypotheses, tectonic and chemical-physical, of the origin of the salt deposits.

Clay and Shale Deposits of the Western Provinces of Canada. By HEINRICH RIES. Trans. Can. Min. Inst., pp. 529–537.

A summary of results of an investigation into the clay resources of the western provinces. It is concluded that the different formations carry a variety of clay resources which it will pay to develop.

Lithia Deposits of the Black Hills. By VICTOR ZIEGLER. Eng. and Min. Journ., Dec. 6, 1913.

Large commercial deposits of lithia occur in the Nancy Peak district of the Black Hills. The occurrence is in the pegmatite dikes, the origin and varied minerals of which are described in detail.

A Barite Deposit near Wrangell, Alaska. By ERNEST F. BURCHARD. U. S. Geological Survey, Bulletin 592–D, pp. 109–117. 1 map. 1914.

A large vein or lens of barite extending parallel to the schistosity of the adjacent rocks and representing the replacement of limestone by barite.

On the Origin of Graphite. By JOHN STANSFIELD. Trans. Can. Mining Inst., 1913, pp. 401–411.

Briefly outlines the several classes of graphite deposits. Describes graphite deposits north of Ottawa River in Buckingham Tp., and shows these to be of igneous origin.

THEORETICAL.

Magmatic Origin of Sudbury Nickel-copper Deposits. By REGINAL E. HORE. Trans. of the Canadian Mining Inst., 1913, pp. 271–281.

Discusses some remarkable analogies between the distribution of copper and nickel in matte and slag, to such distribution in the ore and rock, and finds therein, support for the theory of magmatic segregation from a molten magma.

An Investigation of the Relationships between the Ore Bodies of the Helmskirk-Comstock-Zeehan Region and the Associated Igneous Rocks. By L. LEITH WARD. Proceedings of Section C, Australian Assoc. for the Advancement of Science, Vol. XIII., Sydney, 1911.

In a structurally complex region of Cambra-ordovician and silurian rock, the latter unconformably on the former, granite and more basic differentiates have been intruded at the beginning of Devonian time. Ore deposits have resulted, arranged zonally about certain granite massifs. Cassiterite lodes mainly within the granite borders, magnetite mainly in the contact zone, and pyritic and sideritic veins at a greater

distance from the contact. The inter-relations and gradations of these several ore bodies are emphasized and their common origin in the granite pointed out. The point is made that they are differentiates from a magma which once contained them all, *i. e.*, the granite is one end product, the ore deposits another. The close connection between contact metamorphism and metasomatic replacement of vein walls is maintained and a general plea made for a philosophic genetic interpretation of the entire series of ore deposits as members of a process of differentiation.

The Persistence of Ore in Depth. By MALCOLM MACLAREN. Mining and Scientific Press, Apr. 4, 1914, p. 566.

A review of the occurrence of gold with a view to establishing the factors controlling its persistence in depth. Concludes that where auriferous ore bodies have been deposited by the influence of meteoric oxidizing waters, or by cooling or approach to the earth's surface, they may be expected to diminish in tenor with increasing depth. This generalization appears to apply to the Tertiary andesitic group. All other deposits, especially those of pre-Cambrian group, may be expected to persist unchanged in depth provided the rock of the lode walls is homogeneous and that the ore-bearing fissure does not pass out of that rock. Geological structure as opposed to "depth" is emphasized as a controlling factor.

Classification of the Sudbury Ore Deposit. By A. P. COLEMAN. Trans. Can. Mining Inst., 1913, pp. 283–888, 8 figs.

Discusses the form of the ore deposits in the light of late developments and classifies them as follows: Marginal Deposits; (A) normal, (B) faulted. Offset deposits; (A) columnar, (B) dike-like, (C) parallel.

Sur un gisement de tourmaline daus une serpentine de l'Oural. By L. DUPARC et H. SIGG. Bull. de la Société francaise de Mineralogie, t. XXXVII., Janvier, 1914.

The occurrence of tourmaline in an intrusive mass of serpentine at a limestone contact is of theoretic interest, indicating the presence of "mineralizers" in conjunction with basic intrusions.

STATISTICS.

The Progress of the Mineral Industry of Tasmania for the Quarter ending June 30, 1913. By W. H. WALLACE, Secretary of Mines.

The Mineral Industry of New Jersey, for 1912. Geological Survey of New Jersey, Trenton, N. J., 1913.

The Production of Copper, Gold, Nickel, Lead, Silver, Zinc and other

Metals in Canada in Calendar Year 1912. Dept. of Mines, Mines Branch, Ottawa.

Mineral Products of the United States; Review of Conditions and Output in 1911 and 1912. By EDW. W. PARKER. With a summary of Mineral Production in 1912, by W. T. THOM. Advance chapter from Mineral Resources of the United States for the calendar year 1912, U. S. Geological Survey, 1913.

The Mining and Quarry Industry of New York State, 1912. By D. H. NEWLAND. N. Y. State Museum Bulletin 166.

Mineral Resources of Alaska; Report on Progress of Investigations in 1912. By A. H. BROOKS and others. U. S. Geological Survey, Bulletin 542, 1913, 308 + X. pp., 10 pls., 7 text figures.

REVIEWS

Titaniferous Iron Ore Deposits in Solør (Southeastern Norway) and its Formation through Differentiation Processes. By STEINAR FOSLIE in Norges Geol. Unders. Aarbok, 1913. 51 pp. 2 fig.

The origin of a deposit of titaniferous iron ore in the province of Solør, southeastern Norway, is discussed by Dr. Foslie in an able manner. The first half of the paper is confined to economic conditions and the history of mining which are of local interest and will not be considered here. The latter half of the paper is devoted to the description of the geology and a discussion of the differentiation processes in basic eruptives.

The main mass of the rocks in the province of Solør consists of Archean granites and granite porphyries. The mother rock of the ore is a basic eruptive a mile in extent which is more acid than is usual for this type of deposit and is given the name of quartz-amphibole gabbro. It has the mineral composition of a diorite, the structure and order of crystallization of certain gabbros and an intermediate chemical composition. The order of crystallization is (1) plagioclase, (2) apatite, (3) magnetite, (4) femic silicates, (5) quartz.

Attempt is made to show that the process of segregation as applied to this ore is due to the combined effect of the order of crystallization and gravity. The ore occurs in a zone near, but not at the contact with older granites with a horizontal width as great as 300 feet. The maximum concentration is 85 per cent. (magnetite + ilmenite). It is not concentrated against the plane of contact, as are the magnetic nickeliferous pyrrhotite ores, in which the concentration decreases away from the contact. It is concluded that the concentration of the ore in the melted magma against the cooling plane (Soret's principle) cannot be considered.

The ore has the same mineral composition as the rock except that quartz is wanting. But the order of crystallization is reversed, namely (1) magnetite, (2) amphibole, (3) plagioclase. The plagioclase and apatite show no concentration, but the magnetite shows marked concentration, without any apparent connection with the order of crystallization.

The conditions during the concentration of titaniferous magnetite ores are quite different from those existing during the cooling of a

sulphide-bearing magma in that the magnetite has a higher melting point than the silicates in the magma and there is supposed to exist complete mutual solubility. Thus it is thought that the plagioclase crystallized first until the plagioclase-magnetite eutectic was reached, after which both of these minerals crystallized simultaneously. The specific gravity of the feldspars was about 2.7 and that of the remaining liquid 3.3 or less. But as the magnetite began to crystallize out with the feldspars the solution was enriched in femic silicates, it became less viscose and it decreased in specific gravity. As the magnetite had a specific gravity of about 5 the difference in specific gravity increased rapidly, causing the magnetite to sink.

The downward concentration of magnetite raised the specific gravity in the lower part and the previously formed plagioclase individuals were forced up from the concentration centers leaving only the amount for the eutectic. The crystallization in the main part of the gabbro in the meantime had produced a well-developed, half ophitic texture.

The sinking of the magnetite individuals had been stopped before reaching the bottom of the magma body as the cooling is always a little in advance at the contact. This explains the absence of rich ore immediately along the contact plane itself.

The general conclusion that gravity is a factor which must be taken into consideration in the differentiation of the ores is in accordance with the conclusion of R. A. Daly who has emphasized the importance of gravitative differentiation in several papers.

During the study of the quartz-amphibole-gabbro, Dr. Foslie tried to reach a nearer determination of the "ternary gabbroid eutectic," a term introduced by Vogt to cover the crystallization processes in gabbroid magmas. The results appear on a triangular diagram, which establishes the position of the eutectic point within an area showing 30 to 45 per cent. plagioclase, 35 to 55 per cent. femic silicates and 10 to 20 per cent. magnetite. Vogt places the eutectic between magnetite and plagioclase nearer to the magnetite than this. Dr. Foslie believes that with a decrease in the percentage of femic siliiates, the eutectic between those minerals lies nearer to the plagioclase. He concludes that as the amount of femic silicates increases, the eutectic plagioclase-magnetite becomes constantly more marked, with a greater depression of the melting point.

M. G. EDWARDS.

The Useful Minerals and Rare Ores. By ALEXANDER MCLEOD. John Wiley and Sons, New York, 1914.

This pocket manual of 114 pages is an attempt, more nearly successful than any with which the reviewer is acquainted, "to furnish severely

simple, but fully dependable, means by which any one can determine the useful minerals." The outfit required is fully described and includes only six reagents, a hammer, pocket lens, small magnet, a small iron mortar, two roasting spoons and deep and shallow crucibles. Directions are given for making the roasting spoons and crucibles. The determinative tables which comprise most of the volume are adapted to this small outfit and include 20 elements and about 100 minerals. The minerals are arranged in 11 groups each of which is defined by one or more simple tests.

The book is written primarily for the prospector and most of the tests are such as can be made on a camp fire. A blast lamp and blowpipe would add to the value of the equipment, but as simplicity and lightness of outfit are desired, these are not included, and the many tests dependent upon them are omitted.

The section on the rare ores contains much information of more than passing interest and will be particularly valuable to the prospector searching for these metals. Simple tests for each of the rare ores are given.

It is believed that the book meets a real need of the prospector and that it will be of value to anyone in the field who finds it impracticable to carry a standard blowpipe outfit and larger manual.

J. B. UMPLEBY.

SCIENTIFIC NOTES AND NEWS[1]

PROFESSOR L. C. GLENN, of Vanderbilt University, has spent the past summer examining coal lands in West Virginia. He is also completing a study of the northern half of the coal area for the Tennessee State Geological Survey.

ON MONDAY, November 2, Professor Reginald A. Daly delivered a lecture entitled "Problems of Volcanic Action" before the New York Academy of Sciences at the American Museum of Natural History in New York City.

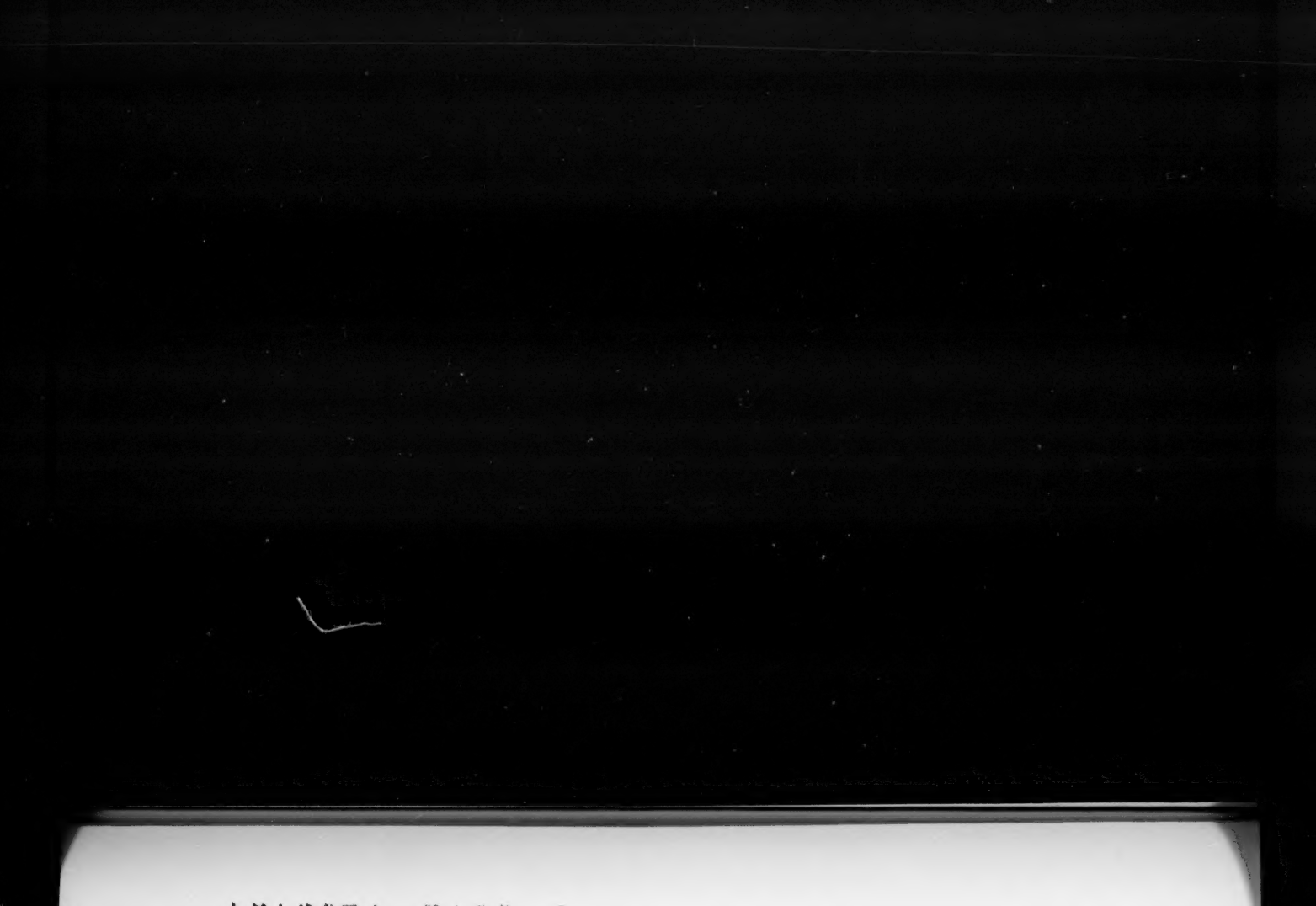
THE WEST VIRGINIA GEOLOGICAL SURVEY has published an interesting report on the upper Freeport coal in a volume just issued.

IN ADDITION to exhibitions of Mining and Metallurgy at the Panama Pacific International Exposition, a special exhibit has been prepared showing the equipment and methods of geological surveys. From the description given in the circular recently issued it appears that geologists will be well repaid for a visit to the exhibition of matters of a geological character which may there be observed.

PROFESSOR A. N. WINCHELL has recently started an experimental course which has for its object instruction in microscopic study of minerals and rocks by correspondence. The work is done under the auspices of the Extension Department of the University of Wisconsin. We are advised that the plan is proving successful. It will certainly be looked upon by geologists with considerable interest.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

AT THE MEETING of the American Institute of Mining Engineers held in Pittsburgh, October 8, 9 and 10, the following papers of interest to economic geologists were read: L. C. Morganroth, "The Occurrence, Preparation and Use of Magnesite"; Ezequiel Ordonez, "Oil Fields of Mexico"; E. C. Harder, "The Iron Industry in Brazil"; H. M. Chance, "The Appraisal of Coal Lands for Taxation." The meeting was interesting and satisfactory.

ON MONDAY, October 5, Professor Douglas W. Johnson read before the New York Academy of Sciences an extremely interesting paper illustrated by charts, maps and lantern slides on the "Topographic Features of Western Europe and Their Influence on the Campaign against France."

A NEW ADDITION to the "Naturalists Directory" has been issued by S. E. Cassion, of Salem, Mass.